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GEOLOGICAL SURVEY OF OHIO

J. A. BOWNOCKER, State Geologist

FOURTH SERIES, BULLETIN No. 29

INDUSTRIAL WATER SUPPLIES OF OHIO

WITH CHAPTERS ON IMPURITIES IN WATER, METHODS OF
ANALYSIS AND THE STATEMENT OF RESULTS AND THEIR
INTERPRETATION, THE BEHAVIOR OF WATER IN USE, AND
THE INDUSTRIAL PURIFICATION OF WATER

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COLUMBUS
1925

Published by authority of the Legislature of Ohio, under
the Supervision of the State Geologist.



Printed by The Kelly-Springfield Printing Company
Springfield, Ohio

F 767;
c.2

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INTRODUCTION

Water is the greatest natural resource of a region; without it the most fertile spot is a desert. As soon, however, as water comes to be used by man its quality as well as its quantity begins to play a role, and as the complexities of civilization increase the role of quality becomes more and more important.

Water may be a carrier of disease and consequently its quality of wholesomeness is an all important one. Typhoid and cholera epidemics have been eliminated from the cities of the temperate zone by water purification plants, watched over by trained chemists and bacteriologists.

In a somewhat analogous way water may also carry industrial diseases which occasion enormous economic losses. These industrial losses brought about by impurities in water are just coming to be realized, and it is therefore fitting that the State should undertake investigations which will do for its industrial life much the same thing that has already been done for the health of its citizens.¹

Such investigations have been taken up by the Geological Survey of Ohio and this Bulletin constitutes the first publication on the subject. Its aim is to present by chemical analyses the nature of the waters of the State from an industrial standpoint and to give some account and discussion of industrial water problems, such as the source and character of the impurities, the methods of industrial water analysis, the behavior of water in use, and the purification of water for industrial purposes.

These topics are presented in their general scientific aspects rather than along the practical, engineering lines of plant experience. This plan was followed because it was appropriate for a general bulletin on the subject, and also because the author has tried always to keep in mind that he is not an engineer experienced in the operation side of water technology but is rather a book and laboratory chemist.

Though some of the matter is necessarily technical, much of it can be read by one entirely without chemical training. Indeed, in the writing of the general chapters the author has kept in mind all who might be attracted by the fascinating lore of water, owners of mills and factories, steam engineers, housewives, and boys and girls with a scientific bent.

¹The State Board of Health of Ohio began in 1898 to study the drinking water supplies of the State and has continued since then the scientific work that has helped to give the cities of Ohio their splendid water purification plants.

For more than anyone else, however, these chapters have been written for those chemists of Ohio whose work is such that they have not had occasion to seek an intimate knowledge of the chemistry of industrial water and do not, therefore, recognize the existence on every hand of industrial water problems. Water problems exist wherever there is a steam boiler, a steam or hot water heating plant, a laundry, or a household, and if chemists have at hand an elementary and detailed presentation of the chemical principles of water technology, the author believes that the solution of the water problems of the State will be promoted as in no other way. This Bulletin, then, will be found to tell little of the practical ways of handling water, but it tries to tell much of the fundamental chemical behavior of water.

As a final word to this Introduction, the author wishes to express his thanks to one of his former students, Mr. Charles P. Hoover, Superintendent of the Columbus Water Purification Plant, for friendly assistance in reading proof and for the valuable suggestions which he has made.

PART I

GENERAL INFORMATION ABOUT WATER AND ITS BEHAVIOR IN USE

CHAPTER I

ORIGIN OF THE IMPURITIES IN WATER

1. Rain water in descending through the air and in percolating through the upper layers of soil absorbs carbon dioxide with which it forms carbonic acid. This greatly increases the solvent power of the water so that it dissolves a certain amount of the mineral matter of the soil and rock with which it comes into contact. The nature of this dissolved matter and also the amount of it which will thus go into solution in a unit volume of water is dependent upon the nature and amount of the mineral matter in the soil and rocks. It thus follows that the character of the waters of a region can be told if the nature of the soil and rock is known, and conversely the general character of the soil and rock can be inferred from the kind and amount of the dissolved mineral matter in the water.

Substances Usually Found in Water

2. Generally speaking, those rocks and mineral particles in the soil that contain the larger amounts of lime and magnesium compounds are the more easily decomposed by water containing carbonic acid, and therefore salts of these metals are likely to predominate in surface and ground waters. The chemical action consists, in the main, in solution as bicarbonates, $\text{Ca}(\text{HCO}_3)_2$ and $\text{Mg}(\text{HCO}_3)_2$. A common exception to this occurs in those regions where there is a great deal of gypsum or calcium sulfate, CaSO_4 . This substance is slightly soluble and always enters the waters where it is present. After calcium and magnesium salts the next most abundant substance in water is likely to be some compound of sodium, usually the chloride or sulfate. This probably comes from the lime-sodium feldspars and certain micas which are abundant in soils and slightly soluble. In many of the deep-seated waters of Ohio, however, the position of sodium is shifted to the top, sodium chloride being the most abundant substance present. This is

evidently due to the presence in the lower strata of deposits of salt resulting from the evaporation of sea water or salt lakes in earlier geologic time. Such waters are really brines, and in addition to their high content in sodium chloride are also characterized by the large amounts of calcium and magnesium salts which they carry. This increase in the concentration of calcium and magnesium salts and of chlorides with the depth of the water-bearing stratum is noticeable in even the shallower wells and of course long before the brine stage is reached.

3. The concentrations of the more abundant acid radicals, or ions, in waters are in the order—bicarbonate, HCO_3 ; sulfate, SO_4 ; chloride, Cl ; and nitrate, NO_3 , with occasional reversal in the positions of sulfates and chlorides.

4. The abundant bicarbonate radical results from the action on carbonate rocks and minerals of the carbon dioxide washed from the air by rain and taken up on the surface and in the upper layers of soil where it is produced by decaying organic matter.

5. Sulfates in waters owe their origin to soluble sulfates, such as gypsum or calcium sulfate, and to the oxidation of decomposed sulfides, such as pyrite.

6. Chlorides occur as deposits of sodium chloride ranging from just enough in the soil to attract herbivorous animals (deer licks), to thick strata of rock salt. Apart, however, from such actual deposits of salt, chlorides in small amounts exist in the soil and rocks though not in sufficient quantity to permit of determining the base with which the chlorine is combined. As the rocks and soil fragments are gradually decomposed, these chlorides are set free and dissolve in the water. In inhabited regions a certain fraction of the total chlorides in the waters comes from animal excreta.

7. Nitrates result from the oxidation of ammonium compounds derived in turn from decaying organic matter. Traces are also found in rain water. Excepting in arid regions there will not be high concentrations of nitrates because of their great solubility and because they are rapidly taken up by growing vegetation.

8. Sulfides are the characteristic constituent of the so-called sulfur waters and owe their origin to mineral sulfides in the rocks and also possibly to the reduction of sulfates by organic matter.

9. Finally, in addition to the constituents given above, which constitute the great bulk of the dissolved mineral matter of Ohio waters, some of the following are usually found in measureable amounts: iron, aluminium, potassium, lithium, ammonia, strontium, barium, manganese, arsenic, phosphates, bromides, iodides, fluorides, and boron. In isolated cases of course any one or any group of the above minor constituents may be present in large quantity. In Ohio, for example, there are many instances of mine waters which carry large amounts of iron resulting from the decomposition and solution of iron pyrite.

10. Iron, though usually present to the extent of a few parts per million only, is included in an analysis because of its importance as an impurity. It is universally present in rocks and soils and probably enters the water as ferrous carbonate.

11. Organic matter is always present in small amount though its determination is not usually included in an industrial analysis. In a sanitary analysis (19) it is roughly measured by the "oxygen consumed" and by the "albuminoid ammonia." The units employed in stating the results of these determinations are, however, such as to give little or no idea of the amount of actual organic matter, for the first gives the amount of oxygen required to oxidize the carbonaceous matter and the second the approximate amount of nitrogen in the nitrogenous matter. The amount of organic material corresponding to these values is much greater.

12. In an industrial state like Ohio mention must also be made of the addition to waters of trade wastes which may add any conceivable constituent, especially to surface waters. This takes place to such an extent that in some instances the character of a fairly large river is dominated by the industrial wastes poured into it.

Natural Changes Taking Place in Water

13. It must also be remembered that the dissolved matter in a water may undergo change. As ground water descends to lower levels, new minerals are encountered or reservoirs containing water with different constituents may be reached with the consequence that some of the mineral matter dissolved from the upper soil will be displaced by new substances existing in greater concentration in the deeper vein. Thus, carbonic acid may be driven out by hydrogen sulfide or the sulfuric acid radical entirely precipitated by an admixture of water carrying soluble barium salts.² In extreme cases the whole character of a water may be changed through the precipitation of its calcium and magnesium as the result of percolating through beds of natural zeolites; in other words a change from hard to soft water will take place. Ohio, however, records no instance of this.

14. Changes in the constituents of waters are, however, not confined to descent into the depths. Coming to the surface whether as a spring or flowing well or when pumped up is also productive of chemical transformations in the constituents of a water. The most conspicuous of such changes is the loss of some of the carbonic acid with the resulting decomposition of the soluble calcium bicarbonate, $\text{Ca}(\text{HCO}_3)_2$, and

²Foulk, C. W., in Geol. Survey of Ohio Fourth Series Bull. 8, Salt Deposits and the Salt Industry in Ohio, p. 27. In the Pomeroy brines sulfates are entirely absent, an unusual condition in Ohio waters but easily accounted for by the presence of barium salts.

precipitation as the normal carbonate, CaCO_3 . Another striking effect observed in many Ohio waters is the precipitation of the iron as a yellowish, brownish flocculent deposit. This is caused by its oxidation from the ferrous to the ferric state by the oxygen of the air and the subsequent hydrolytic precipitation of the ferric iron. An iron-bearing water may, therefore, be perfectly clear when first pumped but will then soon become cloudy or turbid, the particles causing the turbidity presently coalescing, becoming darker, and finally settling to the bottom.

15. If a water contains hydrogen sulfide ("sulfur") in addition to iron, a black precipitate will often form which is sulfide of iron. Hydrogen sulfide alone escapes in part and is oxidized in part by the air with liberation of sulfur which first appears as a white turbidity and then gradually settles out as a dirty looking precipitate. The rate of all changes brought about by exposure to the air will be increased by agitating the water or blowing air through it.

16. Organic matter undergoes a regular series of changes known as the cycle of nitrogen. Assuming the starting point to be the complex substances dissolving from animal or vegetable particles with which the water comes into contact, the first change is to ammonium (NH_4) compounds. Next, under the oxidizing effect of the air and of certain bacteria, these are transformed into nitrites which in turn are rapidly oxidized to nitrates. In order to complete the cycle, the nitrates must be taken up by growing vegetation, which then serving as food can reach the stage of animal matter.

CHAPTER II

MEANING OF WATER ANALYSIS

17. The author has encountered so much misconception of the nature and scope of water analysis that it has seemed worth while to present here some of its fundamental aspects.

18. Most water analyses are made to answer one of the following questions: (1) Is the water safe to drink? (2) Does it contain substances of medicinal value? (3) Is it suitable for industrial use?

Sanitary Analysis

19. The analysis which is made to determine the wholesomeness of a water for drinking is called a sanitary analysis and is for the most part a highly specialized set of determinations, altogether meaningless to the ordinary person, as the following will show:

TABLE I

A typical sanitary analysis

	Parts per million
Total solids.....	530.
Loss on ignition.....	106.
Carbonate or temporary hardness.....	300.
Non-carbonate or permanent hardness.....	70.
Chlorine.....	16.
Oxygen consumed.....	1.9
Albuminoid ammonia.....	0.086
Free ammonia.....	0.022
Nitrites.....	0.002
Nitrates.....	1:2

20. Such an analysis must be accompanied by a description of the surroundings and conditions of the source of the water, that is, of the well, spring, river, or lake under examination. This description of surroundings is called the sanitary survey and it should include all items that might indicate: (1) Whether the water is receiving any sewage, particularly sewage containing wastes incident to human life, and (2) whether the water is receiving any thing that might simulate sewage, that is, contain some of the characteristic substances in sewage.

21. The various constituents listed in the analysis above are

harmless in themselves. They are not the substances in the water which make it unsafe for drinking. The amounts of these constituents of the analysis, however, when considered in the light of the sanitary survey, indicate to the chemist whether the water is receiving any sewage, such for example as seepage from house drains or outdoor privies.

22. If a water can be shown to contain such additions it should be condemned as unfit for drinking, because at any time the sewage may contain the excreta of a typhoid patient and thus all the users of the water may become infected. Lest the more conservative readers may feel that as long as no typhoid patients are in the neighborhood there will be no danger, it may be worth while to point out the aesthetic side of the situation, namely, that no one cares to drink the diluted seepage from his neighbor's privy even though his neighbor is in perfect health.

23. Since this Bulletin is about industrial water, no details of the so-called sanitary analysis will be given.³ The following simple facts, however, should be known to every one.

24. The one thing that makes a water unfit for drinking is contamination by sewage because the sewage may contain specific disease germs. With the exception of an occasional case of lead poisoning due to the action of a very soft water on lead pipes, there is not one chance in millions that a drinking water will contain a poisonous mineral ingredient. If a well or other drinking water supply is suspected, the first thing to look for is the location of house drains, sewers, and outdoor privies. They must be so located with respect to the well that there is no possible chance of contamination.

25. An important point has to do with the employment of a chemist. There is absolutely no use in sending away a sample of water for sanitary analysis unless the one who takes and packs the sample is especially informed on how to do it. The right procedure is to communicate with the chemist first and wait till he sends a prepared bottle for the water, with complete directions for taking the sample and describing the surroundings.

Industrial or Mineral Analysis

26. An analysis for industrial or medicinal purposes is more direct than the sanitary one because the substances in a water which give it its industrial and medicinal properties are capable of direct determination. These substances are almost wholly of mineral character and therefore a complete industrial or medicinal analysis is merely a list of the amounts of the various kinds of mineral matter in the water. Since the latter

³The methods of sanitary analysis are admirably given in *Standard Methods for the Examination of Water and Sewage*, American Public Health Association, New York. (1923).

part of this Bulletin contains hundreds of such analyses none will be given here. It may be said, however, that such an analysis will include the determination of calcium (lime), magnesium, sodium, iron, carbonate, sulfate, chloride, nitrate, and silica. These substances are in nearly every naturally occurring water. Hydrogen sulfide and carbon dioxide are frequently determined and sometimes lithium, potassium, ammonium, barium, strontium, aluminium, bromide, iodide, and phosphate are included. Since water is a universal solvent, very small amounts of almost anything can be found by a chemist who cares to take the necessary time for the search. For example, the author has detected arsenic in many Ohio waters. Timid consumers should, however, not worry over this because there is not enough even to affect the complexion.

27. There is a general belief that many waters have great curative properties. Salts of lithium, bromine, and iodine are supposed to be particularly efficacious in certain disorders. The presence of much magnesium sulfate (Epsom salts) gives a laxative effect. These and other substances can of course be found by the chemist but it is doubtful if the chemist is competent to interpret the results of his analysis from a medical standpoint. Such matters should be referred to a physician. Those who are particularly interested in medicinal waters should consult Bulletin 91, United States Bureau of Chemistry.

28. The advice given in paragraph 25 applies almost as much to those who are seeking a mineral analysis. The chemist should be told the object of the analysis. He will then know what constituents ought to be determined and can advise with his client as to the best procedure.

CHAPTER III

WAYS OF STATING THE RESULTS OF A WATER ANALYSIS

Objections to Hypothetical Combinations

29. Those who have glanced over the tabulated analyses of the ground waters as given in this Bulletin may possibly claim that they cannot understand them on account of the way in which the results are stated. Instead of the familiar calcium carbonate, calcium sulfate, magnesium chloride, etc., there are found separately listed what are apparently the constituents of these well known substances, namely, calcium, magnesium, sulfate radical, etc., "all of which may be scientifically correct but gives no idea of the character of the water." Such a statement of the situation is entirely true, with the qualifications which may be gathered from the succeeding paragraphs, and therefore as a criticism it must be frankly met.

30. During the last decade chemists have begun to drop the old-time method of stating the results of a water analysis in terms of the familiar salts and to give instead the individual constituents. There are two reasons for this: (1) It is impossible and always has been impossible to determine in a solution just how the bases and acids are combined. All that can be done is to determine them separately. For example, the amounts of calcium, magnesium, sodium, sulfate radical, nitrate radical, and chloride can be determined in a water but there is no way of discovering whether the calcium is there as chloride, sulfate, or nitrate, and so on. Indeed, modern chemical knowledge points strongly to the theory that no such combination exists under the conditions. (2) There is no uniformity among chemists as to the methods followed in attempting to combine the bases and acids. For example, one may calculate a set of results so that all of the calcium will be reported as calcium carbonate while another will calculate it nearly all as sulfate.

31. On practical grounds the second reason given above is the more important because no matter how illogical the method might be, if chemists all calculated their results in the same way, all analyses would then be comparable among themselves and users of industrial waters would know through experience just what results to expect from a given analysis. To show, however, that analyses can be and are calculated in different ways and that when so calculated they do not resemble each other to any great degree, the following tables are given. Tables II

and III are from a paper by Dole,⁴ and Table IV gives various ways of calculating the analysis of Sample No. 272 from this Bulletin.

TABLE II

Analysis of the water of Missouri River, near Ruegg, Mo. (Results in parts per million.)

Constituents	Results of analysis
Silica, (SiO ₂)	29.0
Iron (Fe)	0.5
Calcium (Ca)	52.0
Magnesium (Mg)	16.0
Sodium (Na)	31.0
Potassium (K)	6.5
Carbonate radicle (CO ₃)	0.0
Bicarbonate radicle (HCO ₃)	178.0
Sulfate radicle (SO ₄)	104.0
Nitrate radicle (NO ₃)	2.9
Chlorine (Cl)	12.0
Dissolved solids by evaporation	346.0

TABLE III

Analysis of Missouri River water (see Table II), calculated according to various schemes for representing combinations of the ions. (Results in parts per million.)

	1	2	3	4	5	6	7
Silica, SiO ₂	29	29	29	29	29	29	29
Ferric oxide	...	...	...	0.7	...	0.7	0.7
Ferrous bicarbonate, Fe (HCO ₃) ₂	1.6	1.6	1.6	...	1.6	...	...
Calcium bicarbonate, Ca (HCO ₃) ₂	210	210	36	8	126	130	210
Calcium sulfate, CaSO ₄	...	...	147	147	68	68	...
Calcium chloride, CaCl ₂	...	...	...	19	...	...	...
Calcium nitrate, Ca(NO ₃) ₂	...	...	...	...	4	...	...
Magnesium bicarbonate, Mg(HCO ₃) ₂	20	20	96	96	96	96	24
Magnesium sulfate, MgSO ₄	62	62	...	...	...	...	60
Sodium bicarbonate, NaHCO ₃	...	...	94	128	...	...	...
Sodium sulfate, Na ₂ SO ₄	80	80	...	...	83	83	83
Sodium chloride, NaCl	10	13	10	...	10	20	20
Sodium nitrate, NaNO ₃	4	...	4	...	...	...	...
Potassium chloride, KCl	12	9	12	...	12	...	...
Potassium nitrate, KNO ₃	...	5	...	...	...	...	...
Sum	429	430	430	428	430	427	427

⁴Dole, R. B., Hypothetical Combinations in Water Analysis. J. Ind. and Eng. Chem. 6, 710.

32. Mr. Dole makes the following comments on Table III:

"All the sets of combination represent schemes used either by a large number of analysts or by one or two concerns that examine many samples from all parts of the country. The list might be much more extensive. No extreme, but mathematically correct, schemes that are unused have been introduced, and the table has been further simplified by omitting all but the more commonly measured constituents. The only difference between Columns 1 and 2 is that sodium nitrate is calculated in one and potassium nitrate in the other. In Column 3, however, calcium is combined first with sulfate instead of carbonate. In Column 4, calcium is combined successively with sulfate, chlorine, and carbonate. Columns 6 and 7 represent methods used by certain boiler water analysts, who ordinarily determine and report iron as the oxide and do not separate sodium and potassium but compute both together as sodium. As these analysts would not determine nitrate in a water containing so little as that under discussion, absence of that radicle has necessarily been assumed. Bicarbonates instead of carbonates also have been computed because analysis shows that the carbonate radicle is absent; this slight deviation from the directed methods, however, makes no difference in the theory and permits direct comparison with other schemes. According to the scheme in Column 5 calcium nitrate, instead of potassium or sodium nitrate, is computed. According to that in Column 6 as much as possible of magnesium bicarbonate is computed first, while according to that in Column 7 as much as possible of calcium bicarbonate is computed first.

33. "The most obvious deduction from these figures is that it is impossible to compare the report of one analyst with that of another without recalculation. The next thought that comes to most of us is that the other man's scheme is incorrect. Some would object to calculation of calcium nitrate at the expense of calcium carbonate and some to calculation of calcium chloride in the presence of sodium bicarbonate, while others would prefer to calculate magnesium sulfate instead of calcium sulfate. Aside from the theoretical merits of the methods, consideration of which would provoke endless discussion, there are these alarming facts:

34. "(1) All are widely used methods of reporting the analysis of one water. (2) The results can not be directly compared with one another. (3) The results are used for estimating the quality of the water. (4) The results are given to men who, not being chemists, are incompetent properly to discount the statements but take them at their face value."

TABLE IV

Various ways of calculating the analysis of sample No. 272. (Results in parts per million.)

			1	2	3
Calcium, Ca.....	73	Sodium nitrate, NaNO ₃	15	33	29
Magnesium, Mg.....	36	Magnesium nitrate, Mg(NO ₃) ₂ ...	29	13	16
Sodium, Na.....	4	Magnesium carbonate, MgCO ₃ ...	46	105	53
Bicarbonate radical, HCO ₃ ..	299	Magnesium sulfate, MgSO ₄	73	..	73
Sulfate radical, SO ₄	58	Magnesium chloride, MgCl ₂	13	13	13
Nitrate radical, NO ₃	35	Calcium sulfate, CaSO ₄.....	..	82	..
Chlorine, Cl.....	10	Calcium carbonate, CaCO ₃	183	120	183

Iron, Fe, 0.16 parts, and silica, SiO_2 , 38 parts, not included in the calculations.

35. An inspection of the three tables above should convince anyone that a water analysis in which the results are stated in terms of combined salts is of doubtful value to the average water user unless there is some assurance that the method of calculating is the same as that used for other analyses with which he is familiar.

Reasons for Earlier Forms of Statement

36. There are several reasons for this chaotic condition in the reporting of analytical results. First, before the modern theories of water solutions had been developed it was believed that salts in solution still retained the combination of basic and acidic parts though it was recognized that when several salts were dissolved together there might be a rearrangement of bases and acids. Chemists naturally endeavored to find what this rearrangement was under different circumstances. They groped in the dark, however, because the true guiding principle was lacking and as a consequence there was diversity of opinion as to the correct road to follow. Good and bad qualities in a water however soon came to be associated with the presence or absence of some salt and therefore pressure was brought to bear on the chemist so to calculate his results as to make it appear that much or little of a given substance was present. For example, one might imagine the town of Ruegg (See Tables II and III above) seeking to have a certain industry locate there and as an inducement pointing to the desirable quality of the Missouri River water, which according to analyses 1, 2, and 7 contains none of that pernicious, hard scale-forming constituent, calcium sulfate. A rival town, employing a chemist who calculated according to Nos. 3 and 4, might dispute the claim and show that the Missouri was full of dissolved calcium sulfate. Or we might suppose some one had a spring water resembling that of Sample 272, Table IV, in its mineral matter and that it was desired to sell the water because of the medicinal value of the magnesium sulfate, Epsom salts, in it. Such a client would employ chemists 1 and 3 and would have nothing to do with No. 2.

37. This deplorable situation has not of course escaped the chemists themselves and some of them began to calculate their analyses not according to what was supposed to be in the water but *in a way to show how the water would behave under certain circumstances*, for example, when used in a steam boiler. Since the formation of scale is perhaps the most striking characteristic which an analysis of a boiler water is intended to show, the acids and bases were calculated in the way that would show the maximum amount of those combinations which are relatively insoluble. But here again difficulties arise. Boiler scale has a quality as well as a quantity factor and any steam user would prefer within reasonable limits a large amount of soft, loosely adherent scale to a small amount of hard scale that requires a hammer and cold chisel for its removal. How then shall the calculation be made, to show the maximum of the loose scale-producing calcium carbonate, or the hard scale from calcium sulfate?

38. Again, relative solubilities are known only for lower temperatures and pure water as the solvent. What goes on inside a steam boiler running at high pressure and using the average Ohio hard water is still a matter for research; and finally, combinations that would show the behavior of a water under one set of conditions might fail to characterize it when it was used in another way.

39. As would be expected, the net outcome of these diverse opinions has produced different camps of chemists, each believing in its particular method. Each camp too has its followers among the laity, who, because they pay for water analysis, rightly feel that it should be given them in a familiar form. The "combined salts" thus presently crystallized into crusts of conservatism that only recently have begun to dissolve away.

Ionic Form of Statement

40. Turning now to the method which chemists are beginning to use instead of the troublesome combinations, it will be seen that the facts as given in 30, 1, afford the simple and natural way out of the difficulty. Since the individual constituents only can be determined, these are the ones that should be reported in the analysis.

41. There is, though, an added reason which can be brought out better after giving the modern theory of solutions, which states that when salts dissolve in water they dissociate into simpler substances called ions. These ions correspond to the basic and acidic parts or radicals of the salts and are found to be precisely those constituents which the chemist can recognize and determine. In other words, it is the ions only that have the distinctive chemical properties and impart their characteristics to the solution. They exist in the water uncombined and therefore it is nearer the truth so to report them.⁵

⁵An extended discussion of the ionic theory would be out of place in a bulletin of this sort and indeed is unnecessary because at the present time any elementary chemical text book devotes a chapter to it.

42. An example of a prepared solution and its analysis might be worth giving. If small amounts each of calcium sulfate, sodium sulfate, magnesium chloride, and calcium nitrate are dissolved in a large quantity of distilled water so that the solution has about the same amount of salts in it as are present in a hard water, the salts at once dissociate into calcium, sodium, magnesium, chloride, sulfate, and nitrate ions. If the mixture were given to a chemist for analysis he could determine only those ions, and, let us say, would find the following:

Calcium, Ca.....	80	parts	per	million
Magnesium, Mg.....	24	"	"	"
Sodium, Na.....	46	"	"	"
Sulfate, SO_4	192	"	"	"
Nitrate, NO_3	124	"	"	"
Chloride, Cl.....	71	"	"	"
<hr/>				
Total.....	537			

43. This list represents the so-called ionic statement of the results of a water analysis. It gives simply and truthfully what is in the water and contains all the information that can be in an analysis. Owing to its simplicity it is the easiest to follow, and when chemists uniformly adopt it all water results will be comparable among themselves.

44. It is interesting to see what this analysis looks like when calculated according to one of the well-known procedures.⁶

Sodium nitrate, NaNO_3	85.0	parts	per	million
Sodium chloride, NaCl	58.5	"	"	"
Magnesium nitrate, $\text{Mg}(\text{NO}_3)_2$..	74.0	"	"	"
Magnesium chloride, MgCl_2 ...	47.5	"	"	"
Calcium sulfate, CaSO_4	272.0	"	"	"
<hr/>				
Total.....	537.0			

45. Some idea of the progress being made in the use of the ionic forms in water analysis can be gathered from the following: It has been employed for a period of years by the United States Geological Survey.⁷ The Illinois State Water Survey gives its analyses in the ionic form, though accompanying them with parallel lists of hypothetical combinations. A Kansas State bulletin⁸ prints the ionic form only of the mineral analyses of ground waters. In conclusion, the language of Clark might be quoted. He says of attempts to calculate how the bases and acids are combined, "the result is a meaningless chaos of assumptions and uncertainties."⁹

46. Finally, when all the evidence is in, for and against the various

⁶Bartow, Udden, Parr, and Palmer, University of Illinois Bulletin, Vol. 6, No. 3, The Mineral Content of Illinois Waters, p. 38.

⁷U. S. Geological Survey Bulletin No. 616, The Data of Geochemistry, p. 59.

⁸Bulletin of the University of Kansas, Engineering Bulletin No. 5, Water Supplies of Kansas, Part I, Ground Waters, by C. A. Haskins and C. C. Young.

⁹Data of Geochemistry, p. 59.

ways of reporting the results of a water analysis, one important point remains: Whatever its form, the interpretation of the analysis can seldom be made by the layman who lacks special chemical knowledge and experience in such matters. Dole¹⁰ refers to this in the following pointed way:

47. "Rather intimate experience for several years with lay comments on water analyses has made me extremely skeptical as to how much of the truth hypothetical combinations convey to many men who are supposed to make practical use of the results. What the manufacturer or engineer wants to know is how a particular water will fit some use to which he wishes to put it. Is it safe to drink? Does it taste bad? Will it stain clothes? How much scale will it form in boilers? How can it be softened? Answering these questions is the function of an expert, who interprets the facts of analysis in the light of practical experience."

48. The author, feeling the limitations to his own ability to judge from the analysis just what the scaling, corrosive, and foaming properties of a boiler water may be, is disposed to agree with Dole's emphatic statements. The chemist may, and in fact must, make many calculations in arriving at his opinion. The results of some of these ought to be presented in his report, but—and this is the main contention—the report should always contain the ionic statement of the results of the analysis because this and only this gives the fundamental data on which all calculations must be based.

Difficulty of Interpreting Ionic Form

49. There is, however, an inherent difficulty, especially for the layman, in interpreting a water analysis in the ionic form. The chemical effects of the various constituents can not be compared among themselves because these effects are not proportional to the amounts present. In the case of any one ion such a proportionality exists of course but the amount of one ion can not be compared with that of another. The soap destroying power of 24 parts by weight of magnesium is the same, for example, as that of 40 parts of calcium. Forty parts of calcium will combine with 60 parts of carbonate ion to form calcium carbonate but the same amount of calcium will combine with 96 parts of the sulfate ion. Any attempt therefore to judge of the character of a water by inspecting its analysis on the ionic basis must take these facts into consideration. Chemists will at once recognize the situation and say that the different ions have different combining weights. In other words, equal weights of different ions do not exert equal chemical effects. There is some analogy between this and the well-known fact that equal weights of different solids do not occupy equal volumes. Such difficulties are of course simple matters for the chemist. He includes these different combining weights in his calculations. The layman who wishes to use water analyses may now ask a pertinent question—can not the chemist so calculate and state the results of his analysis that the

¹⁰Dole, R. B., J. Ind. and Eng. Chem. 6, 710.

numerical values will be exactly comparable among themselves; so that, for example, if there are five parts of magnesium and five of calcium, it will mean that the soap destroying power of the water is 10, or if there are ten parts of the sulfate ion present it will mean that there is just enough sulfate to combine with the calcium and magnesium? The chemist can do this. All that is necessary is to divide the parts per million of the ions as given in the analysis by their combining weights. The numbers thus obtained are in effect the parts per million of the ions calculated to what the analysis would have been had all of the ions had the combining weight of 1. Since the units of these numbers are all the same from the standpoint of chemical effect, the numbers themselves are strictly comparable. In Table V below an analysis is given calculated in this way:

TABLE V

A Typical Analysis Showing Parts per Million Divided by Combining Weights

Constituent	Parts per million	Parts per million
		Combining weight
Calcium, Ca.....	132	6.57
Magnesium, Mg.....	30	2.47
Sodium, Na.....	45	1.96
Carbonate, CO ₃	289	4.73
Chloride, Cl.....	98	2.76
Nitrate, NO ₃	4	0.06
Sulfate.....	141	2.93

50. The numbers in the last column may now be compared in any way among themselves and of course with similar numbers of other analyses. For example, the soap destroying power is the sum of the numbers for calcium and magnesium, $6.57 + 2.47$ or 9.04. If the water is evaporated it can be seen that both calcium carbonate and sulfate will separate out, because the calcium number is much larger than the carbonate number, and the sulfate number is larger than the difference between the numbers for calcium and carbonate. This reasoning is based on the perfect equivalence of these numbers. The 4.73 carbonate will react with 4.73 calcium. This leaves $6.57 - 4.73$ or 1.84 calcium to form sulfate, which it will do because there is more than that much sulfate. It is interesting to note now that these relations of the calcium carbonate and sulfate ions are by no means apparent from the figures in the second column. These equivalent numbers are thus seen to have very great advantages and one may well inquire why they are not in use. The answer to this question seems to be merely that chemists began to report analyses another way and continued so long that nearly all experience is now founded on that way and it is therefore difficult to change. Nevertheless such equivalents are slowly coming into use. Their value both in interpretation and in calculation is so great that

something of their historical development and examples of their use will now be presented.

The Use of Equivalents in Water Analysis

51. So far as the author is aware, Von Than¹¹ was the first to suggest the use of equivalents in water analysis, but the most comprehensive employment of such numbers is that of Stabler¹² who used them in developing a scheme whereby an engineer with little or no chemical training could interpret a water analysis stated in the ionic form.

52. Stabler called his equivalent numbers reacting values, and instead of obtaining them by dividing the parts per million of the analysis by the combining weights of the ions in question he multiplied the parts per million by a factor called the reaction coefficient of the ion. This reaction coefficient which he called *r* was obtained by dividing the valence of the ion by its atomic or molecular weight. The coefficient for the sulfate ion, for example, is $\frac{2}{96} = 0.0208$. Multiplication by Stabler's reaction coefficients is thus seen to be the same mathematically as dividing by the combining weights.

53. Table VI below gives the reaction coefficients of the ions likely to appear in a water analysis.

TABLE VI
(Atomic weights of 1922)

Positive or basic ions	Reaction coefficient	Negative or acid ions	Reaction coefficient
Aluminium, Al	0.1111	Bicarbonate, HCO ₃	0.0164
Calcium, Ca	0.0499	Carbonate, CO ₃	0.0333
Hydrogen, H	0.9921	Chloride, Cl	0.0282
Iron (ferrous) Fe.....	0.0358	Nitrate, NO ₃	0.0161
Magnesium, Mg.....	0.0822	Sulfate, SO ₄	0.0208
Potassium, K.....	0.0256		
Sodium, Na.....	0.0435		

According to Stabler the symbol of an ion with *r* prefixed means the reacting value of that ion; *r*Ca = 5.52, for example, is read, the reacting value of Ca is 5.52.

54. In Table VII below the complete calculations of the reacting values of the ions according to the analysis of sample No. 33, this Bulletin, is given in order to illustrate the use of reaction coefficients. It will be noted that this is the same analysis used in Table VII.

¹¹Sitzungsberichte der Kaiserl. Akad. der Wissenschaften (Vienna) 51. 2nd Abtheilung (1865), p. 347.

¹²Eng. News 60, 355 (1908). Also U. S. Geol. Survey Water Supply Paper 274, p. 165 (1911).

TABLE VII

The calculation of reacting values from a typical analysis

Analysis No. 33

Constituents	Parts per million	Calculation	Reaction values ¹³
Calcium, Ca.....	132	132×0.0499	6.57 rCa
Magnesium, Mg.....	30	30×0.0822	2.47 rMg
Sodium, Na.....	45	45×0.0435	1.96 rNa
Carbonate, CO ₃	289	289×0.0333	4.73 rCO ₃
Chloride, Cl.....	98	98×0.0282	2.76 rCl
Nitrate, NO ₃	4	4×0.0161	0.06 rNO ₃
Sulfate, SO ₄	141	141×0.0208	2.93 rSO ₄

55. Since in any compound the reacting value of the positive ion is equal numerically to that of the negative ion, the sum of the reacting values of the positive ions in a mixture of salts must equal the sum of the reacting values of the negative ions in the mixture. The accuracy of a water analysis can therefore be checked by the simple process of comparing the sum of the reacting values of the basic ions with the sum of those of the acidic ions. Stabler gives the following method for calculating the percentage error of an analysis on this basis. If rp is the sum of the reacting values of the positive ions, rn the sum of those of the negative ions, and e the percentage error, then

$$e = 100 \frac{rp - rn}{rp + rn}$$

56. In making such a calculation iron and aluminium should be omitted because they are more probably present in the colloidal form than in combinations. The following quotation gives Stabler's discussion of the value of e :

57. "Usually, with fairly careful work, e will not exceed 5 in numerical value for waters containing 100 or more parts per million of dissolved solids, and may generally be expected to be 2 or less. A value of e in excess of 5 will indicate: (1) A blunder in analysis or calculation; (2) if negative, the presence of iron, aluminum, or some undetermined positive radicle; or (3) if positive, the presence of silicate or some undetermined negative radicle. Individual judgment must decide which of these causes of error is the most probable and reject the analysis or correct the form of statement in accordance with the magnitude and character of the error and the relative abundance of the radicles likely to be involved. The correction of an analysis in this manner is generally an unreliable makeshift if the error is large, but can occasionally be made with a high degree of probability."

¹³German chemists called these numbers "milligram equivalents" which nomenclature was also used by Collins, Ind. and Eng. Chem. 15, 394 (1923). Stabler's "reacting values" are, however, now so well established in America that there seems to be no good reason to change.

*Graphical Methods of Representing Water Analysis*¹⁴

58. If strips of paper are cut in lengths proportional to the reacting values (53) of the ionic constituents of a water analysis, one strip for each ion, and if then these strips are laid in two rows, the acids in one and the bases in the other, a graphical representation of the equivalence of the ions according to that analysis will be obtained. Any one of the systems of pairing the acids and bases (70, 74, 76, 78) that are used in calculating hypothetical combinations can be followed, and a picture will thus be given of the relative amounts of the ions entering into each combination. One must not fall into the error, however, of supposing that the lengths of the coinciding portions of a pair of acid and basic strips represent the value of the salt that would be formed by such a combination. The length would have to be multiplied by the appropriate factor from Table XI, 88, in order to obtain that value.

59. The accompanying figure shows two arrangements of the reacting values of the analysis of sample No. 33. The first is according to the Illinois plan (70) and the second is according to a system that will give the maximum amounts of the most insoluble combinations. The inequality of length of the acid and basic row is due to the inevitable errors of an analysis. See 57 for a discussion of such errors. Collins¹⁵ recommends that the errors of closure be distributed between the calcium and carbonate ions. In those analyses in which sodium or carbonate is written in to make a balance (64,2), inequality of length in the graphical diagram never appears.

Na	Mg	Ca
Cl	SO ₄	CO ₃

A

Ca	Mg	Na
CO ₃	SO ₄	Cl

B

60. In the figure, A shows that there is more than enough chloride ion to combine with the sodium and that the magnesium is equivalent to the rest of the chlorine, but is not enough to combine with all of the

¹⁴The author is unable to give the originator of these methods. They were used in the Deutsches Baderbuch in 1907 which in turn gives references to other German sources as early as 1872. See also Collins, Ind. and Eng. Chem. 15, 394 (1923).

¹⁵Collins, Ind. and Eng. Chem. 15, 394 (1923).

sulfate ion. A little of the sulfate must be paired with the calcium the remainder of which counts as carbonate. In B the pairing is done to show the possible amounts of insoluble material.

61. Iron and nitrate are omitted because their amounts in this analysis are too small to be significant in a graphical presentation.

62. If coordinate paper is at hand lines of appropriate length can be drawn almost as readily as strips of paper can be cut.

CHAPTER IV

CALCULATING HYPOTHETICAL COMBINATIONS

63. Those who may have read Chapter III, which argues against the use of hypothetical calculations in the statement of a water analysis, may wonder why a chapter should now be given on the principles and methods used in making such calculations. The answer is simple. Many of those who use, and pay for, water analyses still demand the results in the form of combined salts, and practical chemists should therefore have a thorough understanding of the matter. Secondly, the older published analyses are all in this form, and to understand and interpret them demands a knowledge of how they were obtained. Finally, hypothetical combinations may be used, and indeed are used by many chemists, merely as a method of interpretation, as, for example, when the calculations are intended to show what compounds will separate from the water when it is used in a steam boiler. (See 78.) This is a legitimate use of hypothetical combinations because they then express in a brief and fairly well understood way the behavior of the water under a given set of conditions. The author holds, however, that every such list of hypothetical combinations should be distinctly labeled as an effort to indicate the behavior of the water under the specified conditions so that it will not convey the idea that the combinations actually exist as such in the water, and that, therefore, no other combinations can be considered; and finally that all such interpretative combinations should always be accompanied by the ionic analysis.

General Principles

64. Dole¹⁶ gives three general procedures which are usually followed in calculating hypothetical combinations:

1. All of the acids and all of the bases excepting the alkalis are determined. The acids will then be in excess of the bases and this excess is computed as sodium and potassium salts. In other words, sufficient sodium is written into the analysis to combine with the excess of acid.

2. All of the bases and all of the acids excepting carbonic acid are determined. The bases will then be in excess and this excess is computed as carbonate. In this scheme sufficient carbonic acid is written in to combine with the excess of base.

3. "All the bases and acids are determined and the figures representing the salts are doctored to balance."

¹⁶Dole, R. B., J. Ind. and Eng. Chem. 6, 710.

65. The above methods, it is seen, are bound to balance perfectly. They also conceal errors of analysis in so far as such calculations might disclose them.

66. A fourth method—a variation of No. 3—should be added, namely, one in which all of the acids and bases are determined and the calculated values of the salts are not doctored to balance. If this practice is followed large errors of closure, failure to balance the amounts of the acids and bases as determined, will at least suggest errors in the analysis. (See 55 for method of calculating error of closure.)

67. The actual systems followed in combining the acids and bases can be classified in various ways. In a general sense they fall into two groups, (1) those which pair the ions according to the way they are supposed to be combined in the water, and (2) those which aim to show how the ions will combine as the water is used, for example, when it is evaporated. This second group of systems, it is seen, is merely a method of interpretation. For all practical purposes these two groups can also be described as (1) those in which the salts are so calculated as to give the most soluble ones, and (2) those in which the most insoluble compounds are calculated from the existing ions. Solubility, however, is a matter of conditions. For example, if a water evaporates at or below its boiling point calcium carbonate is the most insoluble substance likely to form. On the other hand, at the temperature of a high pressure steam boiler calcium sulfate is more insoluble than the carbonate. Facts such as these explain in part at least the widely differing systems.

68. The first of these two schemes is the logical one to use, for the calculation of a mineral analysis intended to show the medicinal value of a water. The second method is more commonly employed in industrial analyses, particularly in the case of boiler waters. Perhaps no one adheres strictly to computing the most soluble or the most insoluble of the possible combinations. The general schemes merely are followed.

69. Certain miscellaneous points should be noted. Silica as a rule is not included in the combinations because it probably exists in the water as uncombined silicic acid. It is put down as SiO_2 . Some chemists also do not combine iron and aluminium but report them as Fe_2O_3 and Al_2O_3 . In many surface waters, at least, these metals are present as colloidal hydroxides.

Some actual schemes for making hypothetical calculations will now be given by way of illustration.

Method of the Illinois Water Survey¹⁷

70. The basic and acid ions are combined according to the following table:

¹⁷Bartow, Udden, Parr, and Palmer, Bulletin No. 3, Vol. 6, p. 38.

TABLE VIII

The Illinois System of Combining Acids and Bases

Basic ions	Acid ions
Potassium.....K	Nitrous.....NO ₂
Sodium.....Na	Nitric.....NO ₃
Ammonium.....NH ₄	Chloride.....Cl
Magnesium.....Mg	Sulfate.....SO ₄
Calcium.....Ca	Residual bases to carbonic.CO ₃
Iron.....Fe	
Aluminium.....Al	

71. In using this table one reads down the columns. Potassium is calculated as potassium nitrite. If there is any potassium in excess of that required to combine with the nitrous acid radical present, the excess is combined as nitrate; if there is still an excess, with the chloride ion as potassium chloride and so on down the acid column till all of the potassium is combined. Sodium is next combined with the acid left nearest the top of the column and so on. It will nearly always be the case in this plan that the basic ions will be in excess of the acid ions that are determined. Enough carbonic acid is then finally written into the analysis to combine with the excess of basic ions.

72. Table IX below shows an ionic analysis with the corresponding hypothetical combinations calculated according to this plan. The figures are those of sample No. 8817, page 88, of the Illinois bulletin referred to above.

TABLE IX

Example of a Calculation by the Illinois System

Ions	Hypothetical combinations
Potassium, K..... 9.8	Potassium nitrate..... 0.6
Sodium, Na..... 66.6	Potassium chloride..... 18.2
Ammonium, NH ₄..... .04	Sodium chloride.....169.4
Magnesium, Mg..... 13.9	Ammonium chloride..... 0.1
Calcium, Ca..... 51.5	Magnesium chloride..... 31.6
Ferrous, Fe..... 0.8	Magnesium sulfate..... 21.4
Nitrate, NO ₃ 0.3	Magnesium carbonate.... 13.0
Chloride, Cl .....135.0	Calcium carbonate.....128.6
Sulfate, SO ₄ 17.1	Ferrous carbonate 1.8
Silicon, Si..... 4.8	Silica, SiO ₂ 10.3

73. Since no nitrous acid was present in this water, the potassium was first calculated to the nitric acid and next to the hydrochloric. The large amount of chloride left required all of the sodium and ammonium and part of the magnesium to combine with it. The rest of the magnesium was calculated as sulfate. The sulfate ion was, however, in-

sufficient to combine with all of the magnesium left over from the magnesium chloride, and consequently the last portion was computed as magnesium carbonate. Finally, enough carbonic acid anion (CO_3) was written into the analysis to balance the calcium and iron. Silica is left uncombined.

*Method of Bureau of Chemistry*¹⁸

74. This includes the ions usually determined if the medicinal value of the water is to be estimated. It is given here as a matter of interest rather than for its industrial application.

75. "In calculating the hypothetical combinations of these acid and basic ions, sodium is joined to nitrous and nitric acid, potassium to iodine and bromine, calcium to phosphoric acid, and sodium to metaboric acid. The residual basic ions are then assigned in the following order—ammonium, lithium, potassium, magnesium, calcium, manganese, iron, and aluminium, to the residual acid ions in the following order—chlorine, sulphuric acid ion, and bicarbonate acid ion. In case the bicarbonate acid ion is not present in sufficient quantity to join with all the calcium, the residual calcium is joined to silica to form calcium silicate, and manganese, iron, and aluminium are calculated to the oxides, Mn_2O_3 , Fe_2O_3 , and Al_2O_3 respectively."

*Method of Hale*¹⁹

76. Hale's method assumes that calcium carbonate is the most insoluble one of the possible combinations of the ions in a water and is, therefore, the one that will precipitate first—with calcium sulfate coming next—when the water is evaporated. This necessarily assumes that the water is evaporated at a temperature not much higher than 100°C . At the higher temperatures of a boiler calcium sulfate is more insoluble than calcium carbonate.

77. Hale's system of combining the ions can be expressed as follows (71):

Ca	CO_3
Mg	SO_4
Na	Cl
	NO_3

*Method of French*²⁰

78. French, out of a wealth of experience in interpreting industrial water analyses, follows a system which aims to show what compounds precipitate when the water is evaporated in a steam boiler.

¹⁸Hayward, J. R., Mineral Waters of the United States, Bull. 91 (1905).

¹⁹Hale, J. A. C. S. 29, 1078 (1907).

²⁰French, D. K., Scott's Standard Methods of Chemical Analysis, 3rd ed., Vol. II, 1440. The phraseology of French's method as given here is different from that in Standard Methods cited above. The changes were made largely to bring the matter into conformity with the rest of this Bulletin and are the result of correspondence with Mr. French.

79. If the sulfate and carbonate ions ($\text{SO}_4 + \text{CO}_3$) are more than enough to combine with the calcium and magnesium, that is, if $r\text{SO}_4 + r\text{CO}_3$ is greater than $r\text{Ca} + r\text{Mg}$ (53), the combinations are calculated as follows (71):

Mg	CO_3
Ca	SO_4
Na	Cl
	NO_3

80. If the sulfate and carbonate ions are not sufficient to combine with the calcium and magnesium, that is, if $r\text{SO}_4 + r\text{CO}_3$ is less than $r\text{Ca} + r\text{Mg}$, two cases may arise.

(a) The sum of the acid ions, CO_3 , SO_4 , Cl, and NO_3 , calculated as calcium salts, is materially larger than the total solids dried at 270°F . (132°C). In this case the combinations are calculated according to the scheme:

Ca	SO_4
Mg	CO_3
Na	NO_3
	Cl

(b) The sum of the acid ions calculated as calcium salts as in (a) is materially less than the total solids dried at 270°F . (132°C). This situation suggests a water of unusual composition and calls for more analytical work before a logical calculation of the combinations can be made.

Notes

81. In the above cases correct analytical work is assumed. The same situations may of course be created by mistakes in analysis. It is also assumed that the nitrate ion is included in the analysis. Its omission, however, would not affect cases 79 or 80 (a). Case 80 (b) would result if much nitrate were present but not included in the analysis.

82. The situation in case 80 (a) would result from the presence of magnesium nitrate or chloride. These salts decompose with loss of acid during the evaporation and drying of the residue, which is then lighter than the composition of the water would indicate. The calculation as calcium salts is made because the combining weight of calcium, 20, is near the average of the combining weights of calcium, magnesium, and sodium, the three metals in the water in any quantity. This average is 18.4. The difference of 1.6 is a fair weighting to allow for the fact that calcium is usually present in largest amount.

83. The chemical factors in Table X will be found convenient for the calculation of hypothetical combinations from the analyses in this Bulletin. See, however, the rapid method of calculation in sections 84 to 98 inclusive.

TABLE X

Chemical Factors

(Atomic weights of 1922)

Given	Sought	Factor	Logarithm	Given	Sought	Factor	Logarithm
Ca	CaCl ₂	2.7699	.44246	Cl	CaCl ₂	1.5650	.19451
Ca	CaCO ₃	2.4975	.39750	Cl	KCl	2.1027	.32277
Ca	Ca(HCO ₃) ₂	4.0453	.60695	Cl	MgCl ₂	1.3429	.12805
Ca	Ca(NO ₃) ₂	4.0950	.61225	Cl	NaCl	1.6486	.21712
Ca	CaSO ₄	3.3973	.53114	CO ₂	CaCO ₃	1.6677	.22213
Fe	FeCO ₃	2.0746	.31693	CO ₃	FeCO ₃	1.9306	.28569
Fe	Fe(HCO ₃) ₂	3.1852	.50315	CO ₃	K ₂ CO ₃	2.3032	.36234
Fe	FeSO ₄	2.7203	.43461	CO ₃	MgCO ₃	1.4053	.14777
K	KCl	1.9069	.28033	CO ₃	Na ₂ CO ₃	1.7666	.24714
K	K ₂ CO ₃	1.7673	.24732	HCO ₃	Ca(HCO ₃) ₂	1.3284	.12352
K	KHCO ₃	2.5604	.40831 *	HCO ₃	Fe(HCO ₃) ₂	1.4578	.16370
K	KNO ₃	2.5859	.41261	HCO ₃	KHCO ₃	1.6408	.21507
K	K ₂ SO ₄	2.2284	.34799	HCO ₃	Mg(HCO ₃) ₂	1.1993	.07893
Mg	MgCl ₂	3.9161	.59286	HCO ₃	NaHCO ₃	1.3770	.13893
Mg	MgCO ₃	3.4674	.54000	NO ₃	Ca(NO ₃) ₂	1.3231	.12159
Mg	Mg(HCO ₃) ₂	6.0176	.77942	NO ₃	KNO ₃	1.6306	.21234
Mg	Mg(NO ₃) ₂	6.0994	.78529	NO ₃	Mg(NO ₃) ₂	1.1961	.07777
Mg	MgSO ₄	4.9498	.69460	NO ₃	NaNO ₃	1.3709	.13701
Na	NaCl	2.5417	.40513	SO ₄	CaSO ₄	1.4172	.15142
Na	Na ₂ CO ₃	2.3045	.36257	SO ₄	FeSO ₄	1.5813	.19902
Na	NaHCO ₃	3.6527	.56262	SO ₄	K ₂ SO ₄	1.8141	.25866
Na	NaNO ₃	3.6960	.56773	SO ₄	MgSO ₄	1.2532	.09802
Na	Na ₂ SO ₄	3.0882	.48971	SO ₄	Na ₂ SO ₄	1.4789	.16993

*Rapid Method for Calculating Hypothetical Combinations*²¹

84. The tedious calculations involved in computing hypothetical combinations can be much shortened and made into a routine procedure that can be used by a person without chemical training, for example, an engineer who might want to know the amounts of calcium sulfate, etc., corresponding to one of the analyses in this Bulletin.

85. The method consists in calculating the reacting values (53) and then breaking up the numbers so obtained into portions according to the amounts to be used for the different combinations. If, for instance, the reacting values obtained from an analysis are,

Calcium ion (Ca).....	6.57
Carbonate ion (CO ₃).....	4.73
Sulfate ion (SO ₄).....	2.93

²¹ The author believed for a time that he was the originator of the method of calculating given below but later learned that Dr. Collins and others had used it 10 to 12 years ago in the Water Laboratory of the Bureau of Chemistry but had never published it.

and the system of pairing the acids and bases (70, 74, 76, 78) consists in combining the calcium first as carbonate and secondly as sulfate, the reacting values would be compared and broken up as described below. Before proceeding with details, however, a general principle must be emphasized. The reacting-value units are exactly the same for all ions, and therefore if a given portion of the total reacting value of one ion is used in calculating a combination with another ion, the same numerical amount of the reacting value of that other ion is also used. For example, if the reacting value of the carbonate ion in an analysis is 4.73, it will combine with 4.73 of the reacting value of calcium, etc.

86. By noting that the value for the calcium in 85 above is greater than that for the carbonate ion, it is seen at once that all of the carbonate is to be combined as calcium carbonate and that there will be calcium left over to combine as sulfate. The portion of the reacting value of the calcium that combines with the carbonate is the same as the reacting value of the carbonate ion, or 4.73. The portion left to combine with the sulfate ion is then $6.57 - 4.73$ or 1.84. Since the reacting value of the sulfate ion is larger than 1.84, it is at once seen that all of the calcium not combined as carbonate will be used in combining it as sulfate. Indeed, there will be $2.93 - 1.84$ or 1.09 of the reacting value of the sulfate left to be combined with the same reacting value of something else. The reacting value of calcium, 6.57, is thus distributed so that 4.73 is used to form carbonate and 1.84 to form sulfate. There remains now the method of calculating the parts per million of calcium carbonate and calcium sulfate corresponding to these portions of the reacting value of the calcium.

87. Since the reacting value of an ion is found by multiplying the parts per million as given in the analysis by a factor, it is obvious that the process can be reversed, and by dividing the reacting value of an ion by the factor the parts per million will be obtained. This will apply to a portion of the reacting value equally as well as to the whole value, and if in the above illustration, in which the reacting value of calcium, 6.57, is broken up into two portions, 4.73 to be calculated as carbonate and 1.84 as sulfate, the parts per million of the calcium to be used as carbonate can be found by dividing 4.73 by 0.0499, the reaction coefficient. The amount of calcium so obtained could then be multiplied by the appropriate chemical factor, which is 2.4975, in order to find the corresponding amount of calcium carbonate. In a similar way the amount of calcium sulfate is found by dividing 1.84 by 0.0499 and multiplying by 3.3973, the factor for calcium sulfate from calcium. In practice, however, the two operations, dividing by the reaction coefficient and multiplying by the chemical factor, can be combined into one. The chemical factors are divided once for all by the reaction coefficients. In this way there is obtained a new set of numbers which may be called combination factors. *They are factors for obtaining*

directly from the reacting values the parts per million of the desired combinations. The combination factor for calcium carbonate, for example, is found by dividing 2.4975 by 0.0499. When properly rounded off this is 50.0. In the illustration above, then, 4.73, the reacting value of the calcium distributed to carbonate, is multiplied by 50.0 to get the parts per million of calcium carbonate.

88. A table of combination factors suitable to use with the analyses of this Bulletin has been computed and is given below.

TABLE XI

Combination factors for calculating parts per million of hypothetical combinations from reacting values

Given	Sought	Factor
rCa or rCO ₃	CaCO ₃	50.0
" " rSO ₄	CaSO ₄	68.1
" " rCl	CaCl ₂	55.5
" " rNO ₃	Ca(NO ₃) ₂	82.0
rMg " rCO ₃	MgCO ₃	42.2
" " rSO ₄	MgSO ₄	60.2
" " rCl	MgCl ₂	47.6
" " rNO ₃	Mg(NO ₃) ₂	74.2
rNa " rCO ₃	Na ₂ CO ₃	53.0
" " rSO ₄	Na ₂ SO ₄	71.0
" " rCl	NaCl	58.5
" " rNO ₃	NaNO ₃	85.0

Examples illustrating the use of this table:

$$rCa \times 50.0 = \text{p.p.m. CaCO}_3$$

$$rCO_3 \times 50.0 = \text{p.p.m. CaCO}_3$$

$$rCa \times 68.1 = \text{p.p.m. CaSO}_4$$

$$rSO_4 \times 68.1 = \text{p.p.m. CaSO}_4$$

89. It should be observed that to obtain the parts per million of any compound the reacting value of *either* of its ions may be multiplied by the combination factor. This follows from the fact that the reacting values of the two ions of a compound are necessarily equal numerically.

90. It is also interesting to observe that the combination factors can be calculated by adding the combining weights of the ions of the compounds. For example, the factor for sodium sulfate is $23 + 48 = 71$. In the table the values are rounded off in the first decimal place, which gives ample accuracy for a water analysis calculation.

91. An example of the complete calculation of an analysis will now be presented in Table XII. Each step is indicated and additional explanatory notes are appended.

TABLE XII

Example of scheme for calculating hypothetical combinations from reacting values

Part 1

I System of distributing bases and acids	II Analysis. Parts per mill. of ions	III Calculation of the reacting value. Parts per mill. $\times r$	IV Reacting value
CO ₃ to Ca	CO ₃ 142	142×0.0333	$r\text{CO}_3 = 4.73$
Excess Ca to SO ₄	Ca 132	132×0.0499	$r\text{Ca} = 6.57$
Excess SO ₄ to Mg	SO ₄ 141	141×0.0208	$r\text{SO}_4 = 2.93$
Excess Mg to Cl	Mg 30	30×0.0822	$r\text{Mg} = 2.47$
Excess Cl to Na	Cl 98	98×0.0282	$r\text{Cl} = 2.76$
NO ₃ to Na	NO ₃ 4	4×0.0161	$r\text{NO}_3 = 0.06$
	Na 45	45×0.0435	$r\text{Na} = 1.96$

Part 2

V Distribution of reacting values	VI Calculation of parts per mill. of combination in Column VI	VII Parts per million hypothetical combination
$4.73r\text{CO}_3$ as CaCO_3	$4.73 \times 50.0 = 237$	$\text{CaCO}_3 = 237$
$6.57 - 4.73 = 1.84r\text{Ca}$ as CaSO_4	$1.84 \times 68.1 = 125$	$\text{CaSO}_4 = 125$
$2.93 - 1.84 = 1.09r\text{SO}_4$ as MgSO_4	$1.09 \times 60.2 = 66$	$\text{MgSO}_4 = 66$
$2.47 - 1.09 = 1.38r\text{Mg}$ as MgCl_2	$1.38 \times 47.6 = 66$	$\text{MgCl}_2 = 66$
$2.76 - 1.38 = 1.38r\text{Cl}$ as NaCl	$1.38 \times 58.5 = 81$	$\text{NaCl} = 81$
$0.06r\text{NO}_3$ as NaNO_3	$0.06 \times 85.0 = 5$	$\text{NaNO}_3 = 5$
$1.96 - (1.38 + 0.06) = 0.52r\text{Na}$ in excess		

Explanatory Notes on Table XII

92. Column I shows the system followed in combining the acids and bases (70, 74, 76, 78).

93. Column II merely gives the analysis of the water.

94. Column III gives the complete calculation of the reacting values shown in Column IV. The factors or reaction coefficients used in III are taken from Table VI, 53.

95. Column V gives the method of distributing numerically the reacting values according to the combinations sought. The reasoning according to which the operations of this column are determined is as follows:

96. On turning to Column I of the table it is seen that the CO₃ is to be combined with the Ca, and therefore the reacting values of the two ions are inspected and it is observed at once that $r\text{CO}_3$ is much smaller than $r\text{Ca}$ and therefore $r\text{CO}_3$ may all be calculated as CaCO_3 . This will use 4.73 of the 6.57 of the Ca; therefore the difference, $(6.57 - 4.73)$ or 1.84, is that part of the reacting value of the Ca which can be used in the next combination, the CaSO_4 . Before calculating it as CaSO_4 , however, one

must inspect the reacting value of the SO_4 ion to see if it is as large as 1.84. Since it is 2.93 all of the 1.84 rCa is calculated as CaSO_4 . This leaves, however, an excess of rSO_4 over that required for the 1.84 rCa and this excess ($2.93 - 1.84$) or 1.09 rSO_4 is to be combined with Mg. Since rMg is 2.47 there is more than enough Mg and therefore the 1.09 rSO_4 is all calculated as MgSO_4 . This of course consumes an equal amount of rMg or 1.09 rMg which next must be subtracted from the original rMg to give the amount to be combined as MgCl_2 . This is ($2.47 - 1.09$) or 1.38 rMg. This much rMg consumes in its turn the same amount of rCl or 1.38 rCl which then must be subtracted from the total rCl to obtain the portion to be combined as NaCl. Since rNa is larger than the rCl thus obtained there is some Na left over. A little of it is combined with the NO_3 but there still remains $1.96 - (1.38 + 0.06)$ or 0.52 rNa in excess. This is the error of closure of the analysis. When calculated according to Stabler's formula, (55), it is found to be 2.4 per cent and therefore not excessive.

97. Column VI merely indicates the multiplication of the distributed reacting values by the combination factors, and Column VII gives the final values of the desired combinations in parts per million.

98. Beginners in the use of this new scheme for calculating hypothetical combinations will do well to follow the sequence of operations indicated in the table above. It is particularly important that the matter of Column I be recorded first since it determines the rest of the operations. The order in which the ions of the analysis are recorded in Column II should be related to Column I as shown.

CHAPTER V

METHODS OF CHEMICAL ANALYSIS²²

99. Of necessity this chapter describing the chemical methods employed is technical in character and therefore will be of interest to chemists only. The methods are given with some detail and to a certain extent in the style of a textbook. For this the author makes due apology to those of his brother chemists who are experienced in water analysis. He trusts that they will not try to read them. There are, however, in Ohio many chemists whose duties are quite apart from the chemical technology of water and whose experience along that line is limited. It is these chemists nevertheless who are in the best position to see and to suggest improvements in the use and treatment of the water of their plants, and, therefore, because of their strategic position the methods have been in large part written for them.

100. The rapid volumetric and colorimetric processes of analysis were used instead of the slower and more accurate gravimetric ones because the information wanted was of a general nature only. This choice was also consistent with the fact that as a rule only one sample from a given supply could be taken and it would therefore have been a waste of time to have striven for an accuracy that was within the usual variations of the waters themselves. In the selection of the individual methods, the guiding principles of relative accuracy, time required, and adaptability to the peculiarities of Ohio waters, were followed. No attempt was made to devise new methods, but considerable experimental work was done in connection with some of those employed in order to learn the best conditions for waters of the sort under examination. Some of this experimental work is given in its appropriate place under the individual methods.

Sampling

101. The samples were taken by Mr. DeLong, the assistant chemist, and sent to Columbus in two-quart glass bottles closed with clean corks. At first a number of glass-stoppered bottles were used, but this was soon given up on account of breakage and the glass stoppers were

²²Only those chemical methods which were used in making the analyses published in this Bulletin are given. Chemists who do much industrial water analysis should by all means have Standard Methods for the Examination of Water and Sewage, published by the American Public Health Association. The following books contain chapters or sections on water analyses: Scott's Standard Methods of Chemical Analysis, 3rd ed., D. Van Nostrand; Lunge-Berl, Chemisch-technische Untersuchungs Methoden, 7th ed.; Parr's Analyses of Fuel, Gas, Water, and Lubricants, 3rd. ed., McGraw-Hill.

replaced by corks. The usual amount of sample from one well was one bottleful or two quarts. Precautions were used so that a representative sample of the supply was obtained and not one affected by long standing in the pipes of a pump or by some other plan of handling the water. Strong wooden boxes divided by thin partitions into six compartments were used for shipping the bottles. These boxes were provided with hinged lids that could be closed and locked with a padlock. The experience of a year and a half and the collecting of hundreds of samples proved this to be a safe and easy method of handling the bottles. A few waters that were sent to the laboratory in jugs were transferred to glass to await analysis.

Physical Examination

102. The physical examination was purely qualitative. Turbidity, color, sediment, and odor were noted, but no attempt at quantitative representation was made. The presence of hydrogen sulfide was noted in this way but its amount was not determined.

Method of Reporting Results

103. Water analysis results are usually reported either as parts per million by weight or as grains per United States gallon.²³ The density of the water is assumed to be 1 so that milligrams per liter are equivalent to parts per million. Grains per gallon are found by multiplying parts per million by 0.05834. In many early reports of water analysis in this country results will be found as parts per 100,000. For the reasons advanced in Chapter III, the analyses in this Bulletin are given in parts per million of the constituent ions. As a matter of convenience for those who are more familiar with grains per gallon each analysis is also stated in that way.

Carbon-Dioxide-Free Water

104. Industrial water analysis demands such large quantities of carbon-dioxide-free water that the usual method of preparing it by boiling ordinary distilled water is too tedious. It is best therefore to remove the carbonic acid by bubbling carbon-dioxide-free air through the water. In the Survey laboratory a five-gallon bottle placed on a high shelf above the work table was equipped with rubber and glass

²³There is an extensive literature of water technology from the British Possessions in which "gallon" means the English or imperial gallon which is larger than the United States gallon.

Grains per United States gallon multiplied by 1.2003 equals grains per English gallon.

Grains per English gallon multiplied by 0.8331 equals grains per United States gallon.

tubes in such a way that (1) it could be conveniently filled with distilled water where it stood; (2) by connecting with a suction pump a current of air could be bubbled through, the air being first drawn through a soda-lime tower about an inch in diameter and 15 inches high; and (3) by a change in the connections, water could be siphoned from the bottle, the entering air being kept free from carbon dioxide by passing through the same soda-lime tower. It was found, by passing the air at such a rate that the ascending bubbles could just be counted, that two hours was a sufficient time to reduce the carbon dioxide concentration to such a point that 50 cc. of the water on being treated with phenolphthalein would give a pink color with one drop of 0.1N alkali solution.

Determination of Free Carbon Dioxide

105. The uncombined carbon dioxide in a water may be looked upon as free carbonic acid, H_2CO_3 . It can be determined by titration with sodium carbonate with phenolphthalein as indicator, the reaction being



106. **Solutions.**—(1) N/22 Na_2CO_3 . Pure sodium carbonate is dissolved in carbon-dioxide-free water at the rate of 2.409 g. per liter. The sodium carbonate should be prepared by drying the best sodium bicarbonate to constant weight on a sand bath, taking care, however, not to let the temperature rise above 270°C . Instead of using carbon-dioxide-free water the carbonic acid in ordinary distilled water can be destroyed by slow addition of sodium carbonate till a permanent pink color is produced with phenolphthalein. The carbonate reacts with the carbon dioxide in the water to form sodium bicarbonate which has no effect on the subsequent operations. A quantity of phenolphthalein may be added directly to the water to be treated. The standard solution made by dissolving pure sodium carbonate in this water will have the red color of the indicator but this will in no wise interfere with its use. The solution should be used with the burette connected in closed system with the stock bottle and be protected by a soda-lime guard tube from the carbon dioxide of the air.

107. In field work N/11 Na_2CO_3 is preferable to the more dilute solution because less is required for a titration and a shorter burette may be used. The results are fully as accurate as with the N/22 solution since the end point is sharper.

108. **Procedure.**—The first portion of water taken from the sample bottle should be that for free carbon dioxide. It is drawn from about the center of the bottle by means of a siphon and delivered into the bottom of a Nessler tube (109), 100 cc. being used. Phenolphthalein is then added and the titration made at once with N/22 sodium carbon-

ate solution. Stirring should be done by gentle churning with a long glass rod bent ring-shaped at the end used in the water. The volume of N/22 Na_2CO_3 solution multiplied by 10 gives the parts per million of free CO_2 .

Notes

109. The method of siphoning from below the surface of the water in the large sample bottle and delivering the stream directly at the bottom of the receiving vessel, thus allowing the water to fill up quietly around the end of the siphon, was found to be the one best calculated to avoid loss of carbon dioxide. The least splashing or pouring through the air will cause carbon dioxide to escape.

110. The main difficulty in determining free carbon dioxide lies in sampling. If the water is in a quiet pool so that a sample can be taken from below the surface, accurate and reproducible results can be obtained, but if, as was the usual case with the water analyzed by the Survey, a small stream from a pump or water-pipe is the source of the sample, concordant results can not be expected.

111. During the first part of the work the determination of free carbon dioxide was made in the field with a portable outfit for titration because of the loss of gas that was believed to take place by transporting samples to the laboratory. This plan would perhaps have been continued to the end had not a series of experiments been made to determine the magnitude of this loss. The results of these experiments are as follows:

Serial No. of water	6	7	8	9	10	62	61	60	59	47
Parts per mill. CO_2 determined in field.....	38	22	16	28	34	16.5	14	9	24	5
Parts per mill. CO_2 determined in laboratory.....	40	34	28	43	42	17.0	19	16	16	14

112. Since the whole point in making the determination in the field is to avoid loss due to carrying a sample to the laboratory, the outcome of these experiments was both surprising and disconcerting, for in the majority of the cases *the laboratory sample had more carbon dioxide than was found in the field*. The explanation of this cost some work because it was obscured by the suggestion that the field sample was a better one than that sent to the laboratory. Experiment, however, showed that the contrary was true, the reason being that there was relatively less splashing effect in the taking of the two-liter bottleful than in the 100 cc. portion.

113. This effect of splashing or falling in a stream through the air is well shown by the following experiments. A five-gallon bottle was filled with Columbus hydrant water and carbon dioxide bubbled through it for some minutes. The whole was then mixed and portions taken out for titration as listed below. Nessler tubes holding 100 cc. were used as titrating vessels. They were filled by siphoning as described in 109. This method is referred to below in the phrase "filled from bottom."

TABLE XIII

Results of titrating carbon dioxide as described above

No. of experiment	Method of filling 100 cc. Nessler tube	Vol. N/22 Na ₂ CO ₃
1	Filled from bottom.....	4.6 cc.
2	" " ".....	4.5
3	" " ".....	4.6
4	" " ".....	4.6
5	Filled with splashing.....	4.1
6	Same as No. 5.....	4.1
7	Filled from bottom.....	4.5
8	Filled by holding finger over lower end of siphon to cause stream to squirt out.....	3.6
9	Same as No. 8.....	3.7
10	Filled from bottom.....	4.6
11	Filled by having lower end of siphon on level with top of Nessler tube.....	4.2
12	Filled by letting stream from siphon fall 42 inches.....	2.8
13	Filled from bottom.....	4.6
14	Six 100 cc. tubes filled from bottom and allowed to stand exposed to air but without agitation	
14.1	After standing 10 minutes.....	4.4
14.2	" " 15 ".....	4.4
14.3	" " 20 ".....	4.4
14.4	" " 25 ".....	4.4
14.5	" " 30 ".....	4.4
14.6	" " 35 ".....	4.3
15	Filled from bottom.....	4.5

114. Experiments were also made to show the effect of allowing the water to stand in the laboratory in the 2-liter sample bottles when they were filled to the top excepting an air space of about 20 cc. under the cork. Water from the carboy as described above was used. It was filled into the 2-liter bottles from the bottom up and was titrated immediately before the filling. After standing, the bottles were opened and 100 cc. portions were siphoned out for analysis. The original water in bottle No. 1 contained 46 parts per million carbon dioxide and after 19 hours two titrations showed 44 and 43 parts respectively. Bottle No. 2 contained 44 parts of carbon dioxide and after 43 hours standing this had fallen to 42 parts. Bottle No. 3 fell off in 11 days from 44 parts to 40 parts. These losses are much smaller than the differences between the field and laboratory results as shown in paragraph 111. The case, however, is different if the bottle is not full. The sample for carbon dioxide must be the first one withdrawn because experiments showed a serious loss from the water in bottles which stood for a day or so after portions had been taken out for other analyses.

115. After the effect of splashing had been studied, efforts were made to devise a method that would avoid the trouble while taking the sample. Rubber tubes of different sizes were carried to be attached

to the water outlets encountered so that the 100 cc. Nessler tube could be filled from the bottom. The water outlets, however, varied so much that this plan was given up and the idea of the field analysis was finally abandoned altogether. Since the experiments of Table XIII above showed that the loss was relatively less with the larger sample in the larger bottle this was the only one taken and the free carbon dioxide was determined in the laboratory. In taking the 2-liter sample, splashing was of course avoided as much as possible.

116. The suggestion naturally arises that the higher content of carbon dioxide in the large laboratory samples might have been due to a partial decomposition of the bicarbonates. This hypothesis, however, does not seem tenable on theoretical grounds and furthermore a deposit of calcium carbonate was not observed. Finally it should be said that no claim is made here that the samples taken as described above are perfectly accurate. They are merely more accurate than the 100 cc. field samples were and are sufficiently accurate for the purposes of the Survey.

Hardness

117. From the facts outlined in paragraph 256 it is seen that the total hardness of a water is measured by the concentration of calcium and magnesium, independent of the negative elements or radicals in combination with them, but that the nature of the hardness, whether it is the carbonate or non-carbonate variety, is due to the character of the negative elements combined with these metals. Combinations with the bicarbonic acid radical, $\text{Ca}(\text{HCO}_3)_2$ and $\text{Mg}(\text{HCO}_3)_2$, produce the carbonate or temporary hardness and all other combinations, the most common being the sulfates, chlorides, and nitrates, give rise to non-carbonate or permanent hardness.

118. Since all of these combinations commonly exist together in a water, the chemist's problem is to find methods for the following: (1) The determination of total calcium and magnesium. (2) The determination of the calcium and magnesium present as bicarbonates. (3) The determination of calcium and magnesium in combinations other than as bicarbonate. On the assumption that all results will be calculated to the common basis of equivalent concentration of calcium carbonate (125) it is obvious that if any two of these three values are known the third can be found by simple addition or subtraction.

119. The most accurate method for obtaining the total hardness is by gravimetric determinations of the calcium and magnesium. This is, however, seldom used in routine water analysis because of the time consumed but it should be emphasized that it is the court of last resort and should be employed in cases of doubt or where the results obtained by other methods are peculiar in any way. The volumetric estimation of the calcium and magnesium can be considered next in point of accuracy and is the method finally adopted by the Survey.

120. Another commonly employed volumetric scheme consists in precipitating the calcium and magnesium together, with an excess of a standard alkaline solution, the so-called "soda-reagent." The excess of this reagent which remains unacted upon by the calcium and magnesium is then determined by titration with standard acid. This plan has the advantage of determining the two hardness-forming metals together as a unit which is sufficient for many purposes. In water softening operations, however, and as an aid in interpreting the results, it is necessary to know the total magnesium by itself; consequently the plan has no advantage over the separate determinations of calcium and magnesium and, it should be added, is not so accurate.

121. The oldest method for determining total hardness takes advantage of the effect of the dissolved calcium and magnesium salts on soap. Since hard water destroys soap and prevents the formation of a lather, the suggestion came early to measure the degree of hardness by titrating the water with a standard soap solution, taking the appearance of a permanent lather as the end-point. This has the advantage of simplicity and in the case of relatively soft waters and especially with those containing little or no magnesium salts, it may be called a good method. With very hard waters high in magnesium it is unreliable and should not be used.

122. For distinguishing the carbonate from the non-carbonate hardness two general plans are in use. (1) The bicarbonates are decomposed by boiling, carbon dioxide being lost and the normal carbonates precipitating according to the reactions,



The precipitate can be filtered off and analyzed for calcium and magnesium or these metals can be determined in the filtrate and their amount, calculated as calcium carbonate (125), subtracted from the total hardness. (2) The bicarbonates are titrated with a standard acid. Both methods are open to criticism though the second one has better standing than the first. Owing to the fact that calcium carbonate is more insoluble than magnesium carbonate, the latter does not precipitate to any great extent on boiling the water if there is present an excess of a soluble calcium salt like the chloride or sulfate (497).

123. The objection that can be made to the titration of the bicarbonates with standard acid is that such a titration really measures the total alkalinity of the water and since ground waters containing an excess of sodium bicarbonate are frequently encountered, and in the examination of softened waters, alkalinities due to excess of lime or soda ash are not uncommon, serious error might result. This situation is discussed in paragraphs 164, 165, and 166.

124. In the analytical work of the Survey the "soda-reagent" method for total hardness was used at first, more as a matter of habit than for any other reason. A separate determination of magnesium was made and the calcium was obtained by subtracting the magnesium from the total hardness. After some time, however, it was realized that a separate determination of calcium could be made in even less time than was required for the total hardness, and since the results were more accurate the change was made. The soda-reagent plan, however, is described because it was employed during the first part of the work.

125. Hardness from whatever cause is reported in terms of calcium carbonate. This means that both magnesium and calcium salts are calculated as the equivalent amount of calcium carbonate. For example, if a water contains 75 parts per million of magnesium the corresponding amount of calcium carbonate can be found by the following equation:

$24.32 \text{ (At. wt. of Mg.)} : 100.07 \text{ (Mol. wt. of CaCO}_3\text{)} :: 75 : X \text{ (pts. per mill. of CaCO}_3\text{)}$

126. In addition to parts per million, hardness is also given in grains per U. S. gallon or in certain arbitrary units called degrees. Of these latter, the English or Clark degree is equivalent to one grain of calcium carbonate per English gallon; the French degree equals one part of calcium carbonate per 100,000, and the German degree is one part per 100,000 of calcium oxide, CaO. Parts per million multiplied by 0.07 equals Clark degrees; by 0.1 equals French degrees; and by 0.056 equals German degrees.

Determination of Magnesium

127. **Solutions.**—(1) Lime water. An excess of slaked lime should be shaken with the desired volume of water till the saturation point is reached. This mixture is then allowed to settle and the clear, supernatant liquid siphoned into a clean bottle. To prevent a possible precipitation of calcium hydroxide, due to changes in temperature, 10 cubic centimeters of distilled water is added for each liter of lime solution.

(2) Standard acid. 0.05N HCl or H₂SO₄ (See 132).

128. **Procedure.**—One hundred cubic centimeters of water is measured into a 200 cc. graduated flask and titrated with hydrochloric or sulfuric acid with methyl orange (135) as indicator. When the end-point is reached the liquid in the flask is boiled for 15 minutes to expel carbon dioxide, and then to the hot solution 50 cc. of lime water is added (136). The flask is next stoppered and the contents mixed and

cooled to room temperature, after which carbon-dioxide-free water is filled in to the mark and a final thorough mixing given. If the precipitate produced by the lime water does not settle readily, the flask should be set on the water bath for 10 minutes. If this is done the liquid is next allowed to cool till the meniscus is again at the mark, when 100 cc. is pipetted out and the excess of lime water determined by titration with standard acid with methyl orange as indicator.

129. At the same time that the analysis is being carried out the relation between the lime water and the standard acid is determined in another flask by "running a blank." A good procedure is to start with about 100 cc. of ordinary distilled water, boil it 15 minutes, and then add the measured portion of lime water. After cooling the mixture to room temperature, carbon-dioxide-free water is added to the mark, and after mixing, 100 cc. is pipetted out and titrated.

130. If A equals the cubic centimeters of 0.05N acid used in titrating lime water in 100 cc. of blank solution, and B equals the cubic centimeters of 0.05N acid used in titrating excess of lime water in 100 cc. of solution of the sample, $(A-B) \times 50$ equals parts per million of Mg. in terms of CaCO_3 (125). This is the form in which the magnesium is wanted for calculating the total hardness. To get the amount in terms of the element itself, that is, Mg., the CaCO_3 equivalent as obtained above is multiplied by 0.243.

Notes

131. Building lime may be used in the preparation of the lime water. The fact that such lime is contaminated with magnesia is of no consequence because the calcium hydroxide precipitates it. It is sometimes inconvenient, however, to obtain a small quantity of fresh lime and therefore it is worth remembering that a pure calcium oxide can be made in the laboratory by heating over the blast lamp a few grams of the calcium carbonate employed as a reagent in the J. L. Smith method for determination of the alkalis.

132. In the various methods for the determination of hardness, the standard acid is the ultimate measuring device and it must therefore be accurate, and since all hardness results are given in terms of calcium carbonate, 1 cc. of the standard acid should be equivalent to an amount of calcium carbonate that will be convenient for calculating the final result. It is customary to choose such a volume of the water to be analyzed and such a strength of standard acid, that multiplying by a simple factor will give the final result in parts per million or grains per gallon as the case may be.

133. In the above procedure for magnesium only half of the excess of lime water is titrated and therefore the volume of standard acid used refers to one-half of the original water sample, or to 50 cc. By subtracting this from the volume of acid required for the blank, where also only one-half is titrated, the amount equivalent to the magnesium in 50 cc. of water is found. This multiplied by 20 gives the volume of standard acid that would be required were a liter of water to be titrated. If now this amount be multiplied by the value of 1 cc. expressed in milligrams of equivalent

calcium carbonate the number of milligrams per liter of calcium carbonate will obviously be obtained or, in other words, the parts per million. The final formula is then developed as follows: A equals cubic centimeters of 0.05N acid to titrate excess of lime water in half of "blank." B equals cubic centimeters of 0.05N acid to titrate excess of lime water in half of sample. $A - B$ equals cubic centimeters of 0.05N acid equivalent to Mg in 50 cc. of sample. 50 cc. equals $\frac{1}{20}$ of liter. 1 cc. of 0.05N acid equals 2.5 milligrams CaCO_3 . $\therefore (A - B) \times 20 \times 2.5 = (A - B) \times 50 =$ milligrams per liter of CaCO_3 equivalent to Mg in one liter of sample = parts per million.

134. If the results are wanted in grains per U. S. gallon, parts per million must be multiplied by 0.05834. In some cases grains per gallon is the only form in which reports will be received and if many analyses are made it will save time to make the standard acid of such strength that 1 cc. of it will be equivalent to some small whole number of grains. According to the formula which applies to the above procedure, if $A - B$ equals 1 cc. there will be the equivalent of 50 parts per million of calcium carbonate in the water. $50 \times 0.058335 = 2.917$ gr. per gallon. This is very close to 3 grains so that a slight modification of the strength of the acid will make 1 cc. under the above conditions equal 3 grains per gallon. This strength of acid is obtained by multiplying 0.05N by $\frac{3.000}{2.917} = 0.0514\text{N}$. If the normality basis is confusing, the calcium carbonate value of 1 cc. (2.5 mg.) can be multiplied by the same factor, which will give 2.571 mg. calcium carbonate as the value of 1 cc. The final formula would then be $(A - B) \times 3$ equals grains per gallon.

135. If methyl orange is used as indicator there will be no interference with the subsequent reactions due to its presence. If erythrosine were employed the chloroform (162) might introduce complications.

136. Experiments were made to determine the proper amount of lime water by using waters ranging from less than 100 to over 300 parts per million of magnesium calculated as calcium carbonate. Very little difference was found between the results with 25 cc. and those with 50 cc. of lime water. It seemed nevertheless desirable to use the larger amount.

Determination of Calcium

137. **Solutions.**—(1) Standard Potassium Permanganate. This should be 0.04N and is best standardized against pure sodium oxalate.

(2) Saturated solutions of ammonium chloride and of recrystallized oxalic acid.

138. **Procedure.**—One hundred cubic centimeters of the water is measured into a beaker, a few drops of methyl orange added and then dilute hydrochloric or sulfuric acid till the indicator shows the acid reaction. A 10 cc. portion of the ammonium chloride solution is next put in and the whole heated to boiling (140). The calcium is then precipitated by adding 5 cc. of saturated oxalic acid solution followed by dilute ammonium hydroxide (1 : 20) in small portions at a time with stirring till the methyl orange shows an alkaline reaction. To increase the size of the precipitate particles the beaker is set on a water bath or hot plate for an hour (141) after which the calcium oxalate is filtered onto asbestos (142) and washed with hot water. Both precipitate and asbestos felt are then transferred to the beaker in which the precipitation was made. The volume of liquid is made up to about 100 cc., 5 cc. of

concentrated sulfuric acid is added (143) and the mixture warmed if necessary, and the oxalic acid set free titrated with the 0.04N KMnO_4 solution. The number of cubic centimeters used multiplied by 20 gives the equivalent parts per million of calcium carbonate. For the calculation of the equivalent amount of calcium, see Table XV, 197.

Notes

139. Sodium oxalate suitable for standardizing is very difficult to make in the glass and porcelain ware of the ordinary laboratory and it should therefore be purchased under a special guaranty of purity, preferably from the Bureau of Standards at Washington, D. C.

140. The calcium oxalate was first precipitated in the cold and the solution afterwards heated. When done in this way, however, there was a great deal of trouble due to the calcium oxalate running through the filter. Precipitating hot avoided this.

141. If only one or two determinations are made at a time the solutions after precipitation of the calcium oxalate can be boiled for three or four minutes instead of digested on the water bath for an hour. Great care must however be used to prevent bumping.

142. In the work of the Survey porcelain Gooch crucibles with detachable bottoms were used. This arrangement greatly facilitates the transfer of the precipitate and asbestos felt.

143. By using concentrated sulfuric acid the solution as a rule becomes warm enough for the permanganate titration.

144. The amount of magnesium usually found in even a very hard water will not interfere with the precipitation of calcium oxalate. If it is present in large excess the solution must stand ten or twelve hours before filtering and the precipitate must be dissolved and reprecipitated. In such extreme cases, however, gravimetric procedures should be used.

Total Hardness by Means of Soda Reagent

145. **Solutions.**—(1) Soda Reagent. This consists of a mixture of equal volumes of sodium carbonate and sodium hydroxide solutions, the exact strength of which depends upon the average hardness of the waters to be examined (149 to 152). That used by the Survey was 0.4N. It need be approximate only, and is made by preparing separately the two solutions which should not differ in strength by more than 2 or 3 per cent, and then mixing them volume for volume.

2. Standard acid. 0.05N H_2SO_4 or HCl (132).

146. **Procedure.**—To 200 cc. of water in an Erlenmeyer flask of some form of resistant glass, sufficient standard acid is added to neutralize the bicarbonates after which the whole is boiled down to approximately 100 cc. (154), as determined by a mark on the flask. A 50 cc.

portion of 0.4N soda reagent is then added and the mixture again boiled down to 100 cc., after which it is transferred to a 200 cc. graduated flask, cooled, diluted to the mark with carbon-dioxide-free water and mixed. The solution is next filtered, rejecting the first 40 to 50 cc., and 100 cc. of the clear filtrate is transferred to a flask and the excess of soda reagent titrated with the 0.05N acid (155), with either methyl orange or erythrosine as indicator.

147. To get the value of the soda reagent in terms of the standard acid a blank is run by boiling down 200 cc. of distilled water to 100 cc., adding 50 cc. of soda reagent, again concentrating to 100 cc., transferring to a 200 cc. graduated flask, diluting with carbon-dioxide-free water, filtering, etc., exactly as in the determination, and finally titrating with the 0.05N acid.

148. Owing to the fact that the solutions are divided, it is seen that the amount of sample actually analyzed is 100 cc., and that the amount of soda reagent actually titrated in the blank is the same as that which acts on 100 cc. of the water. The calculation may then be based on 100 cc. of sample or one-tenth of a liter. If A equals cubic centimeters of 0.05N acid equivalent to the soda reagent titrated in one-half of the "blank" solution, and if B equals cubic centimeters of 0.5N acid required to titrate the excess of soda reagent in one-half of the solution of the sample, or in 100 cc. of the sample, then $A - B \times 2.5 \times 10 =$ parts per million of calcium and magnesium salts, or the total hardness in terms of calcium carbonate. (For the derivation of a formula similar to this one, see 133.) If the titration of the sample requires more acid than the blank, that is, if A is less than B, the water contains alkaline carbonates. See 165 and 166 for a discussion of this situation.

Notes

149. Many textbooks on water analysis call for 25 cc. 0.1N soda reagent for 200 cc. of sample. This is too weak for very hard waters like those in Ohio and therefore either a smaller volume of water must be used or more soda reagent in order to get the proper mass action effect to render the calcium and magnesium salts insoluble. To avoid the tedious boiling down of large volumes of liquid, a stronger reagent was employed in the work of the Survey rather than a larger volume of the 0.1N solution.

150. The following table shows the effect of varying the concentration of soda reagent. Results are given in parts per million of equivalent calcium carbonate. Two hundred cubic centimeters of water was used in each experiment.

TABLE XIV

Water analyzed	5 cc.	10 cc.	15 cc.	20 cc.	25 cc.
	0.5N	0.5N	0.5N	0.5N	0.5N
	soda	soda	soda	soda	soda
	reagent	reagent	reagent	reagent	reagent
	equiva- lent to 25 cc. 0.1N	equiva- lent to 50 cc. 0.1N	equiva- lent to 75 cc. 0.1N	equiva- lent to 100 cc. 0.1N	equiva- lent to 125 cc. 0.1N
Ohio State University spring water.....	{ 450 438	{ 445 441	{ 456 456	{ 450 456	{ 456 460
Water from Bellevue, Ohio..	{ 588 588	{ 908 908	{ 933 933	{ 938 938	{ 925 925
Well water from Columbus, Ohio. Serial No. 8.....	{ 577 577	{ 701 701	{ 716 712	{ 724 712	{ 732 725

151. In these experiments a strong soda reagent was used in order to avoid the large volumes of liquid that would have resulted from the equivalent amounts of 0.1N solution. It is seen from the results that 25 cc. of 0.1N soda reagent is inadequate in the case of the Bellevue and No. 8 waters though it serves very well for the softer spring water. The very hard waters require the equivalent of 75 cc. of 0.1N soda reagent to precipitate their total hardness.

152. Since the method at its best depends so much upon the conditions of the experiment it was deemed advisable in the work of the Survey to use a very large excess of the soda reagent so that the reduction in its concentration by the calcium and magnesium salts in the water would be relatively small, in other words, the concentration of soda reagent would be nearly a constant in all determinations. To this end the strength finally selected for use was 0.4N and the amount employed for each determination was 50.0 cc.

153. The amount of acid to neutralize the bicarbonates can be determined by titrating the 200 cc. portion with methyl orange as indicator or just twice the volume of acid required for the titration of 100 cc. in the determination of alkalinity can be put in without the use of an indicator.

154. The prolonged boiling and consequent concentration serves the double purpose of driving out all carbon dioxide and insuring the complete precipitation of the calcium and magnesium salts.

155. Since the standard acid used in titrating the soda reagent is only 0.05N, it can be seen that over 100 cc., or several 50 cc. burettefuls of acid would be required to titrate the excess of soda reagent. To obviate this difficulty without detracting from the accuracy of the measurements, 25 cc. of a stronger acid was added before beginning the titration with the standard 0.05N acid. This stronger acid was of such concentration that the titration could be finished with one buretteful of the 0.05N acid. Both accuracy of measurement and time were conserved by using an all-glass constant delivery pipette for the introduction of the stronger acid. Such an instrument is more nearly constant in delivery than an ordinary pipette.

156. Those who are interested in the art of planning the details of an analytical process will note that neither the exact strength nor the exact volume of the portion of stronger acid need be known. The

only requirements are that the strength and volume shall be convenient for the purpose in hand and that they do not vary from one titration to another.

Carbonate Hardness

157. **Solutions.**—Standard acid. Either 0.05N HCl or H_2SO_4 may be used (132).

Erthyrosine indicator. Erthyrosine is dissolved in water at the rate of about 50 milligrams per 100 cc. It does not keep well, especially when exposed to the light, and should therefore be freshly prepared at least once a week.

158. **Procedure.**—(1) With methyl orange indicator. One hundred cubic centimeters of the water is titrated in any suitable vessel with the 0.05N acid. A similar vessel containing the same amount of water and indicator will aid greatly in noting the end-point (161).

159. (2) With erthyrosine indicator. One hundred cubic centimeters of sample is measured into a 250 cc. glass-stoppered bottle of clear white glass. About 5 cc. of chloroform (162) and 2.5 cc. of indicator solution are then added and the titration begun. After each addition of the acid the stopper is replaced and the bottle shaken vigorously so as to distribute the chloroform in droplets through the water. The end-point is the disappearance of the rose color. A comparison bottle will aid greatly in recognizing the change in color.

160. The carbonate hardness of the water in parts per million of calcium carbonate is found by multiplying the number of cubic centimeters of 0.05N acid used by 25. (See 133 for the derivation of such formulas.)

Notes

161. The author has at times experienced much trouble with the methyl orange end-point, due to a poor product. In buying methyl orange therefore it should be specified that it is to be used as an indicator. Even with good material the end-point is strongly affected by the concentration of the indicator used. As a rule too much is added and it is to be recommended that various amounts be tried till the depth of color is found that will give the most sensitive color change. Finally it should not be forgotten that the solution deteriorates slowly on standing.

162. Without the chloroform or some other suitable, non-miscible liquid present, the erthyrosine end-point would be worthless. The chloroform must be tested for acidity by shaking a portion with water and testing the water. If found acid it should be washed by shaking with successive portions of water till the washings are neutral

Non-carbonate Hardness

163. The non-carbonate hardness of a water is found by subtracting the carbonate hardness from the total hardness. It may also be determined directly by the following modification of the soda reagent

method. Instead of neutralizing the bicarbonates in the samples of water, as described for the determination of total hardness, the water is simply boiled ten minutes to precipitate the carbonate hardness. Soda reagent is then added and from that point the procedure is the same as for total hardness. If the water contains sodium carbonate the sample will require more acid for its titration than the "blank."

Alkalinity Caused by Carbonate or Bicarbonate of Sodium or by Calcium Hydroxide

164. Many natural waters in the middle or western states contain sodium carbonate or bicarbonate and in the careless softening of water with lime and soda ash, the treated water may contain an excess of sodium carbonate or bicarbonate or of calcium hydroxide. All of these substances impart alkalinity to the water and therefore might easily be confused with carbonate hardness.

165. Fortunately a comparison of the total hardness with the carbonate hardness as determined by titration with standard acid will at once indicate the presence of sodium carbonate. *The total hardness will be less than the carbonate hardness.* If the non-carbonate hardness is determined directly by the soda-reagent method after boiling the water (163), the presence of alkali carbonates will be shown by the fact that the sample will require more acid for its titration than the "blank." This will of course not be the case if the total hardness is determined by soda reagent because any sodium carbonate present would be neutralized by the acid added to destroy the bicarbonates.

166. The presence of carbonates or hydroxides can also be shown by adding phenolphthalein to the water. This indicator is not affected by bicarbonates but gives its characteristic red color with normal carbonates and hydroxides. In this connection it must not be forgotten that calcium carbonate is sufficiently soluble to redden phenolphthalein and therefore a water in which a part even of the bicarbonates has been precipitated will give the test. See 448 for the barium chloride test for carbonates.

167. The only reliable method for distinguishing the nature of the alkalinity of a water is by making titrations with standard acid using at one time an indicator like methyl orange or erthyrosine that changes color at a relatively high hydrogen ion concentration and the other time an indicator like phenolphthalein that changes at a low hydrogen ion concentration and therefore does not give its alkaline color in the presence of bicarbonates alone. The behavior of these two groups of indicators can be summarized as follows:

168. Methyl orange and erthyrosine give their alkaline color in the presence of carbonates, bicarbonates, and hydroxides, and change to the acid color when these substances have been completely neutral-

ized. Phenolphthalein gives its alkaline color in the presence of carbonates and hydroxides but remains colorless (acid color) in the presence of bicarbonates. Consequently its end-point comes when all of the hydroxide and half of the carbonate have been neutralized. The quantitative relations are given below.

169. ME equals volume of standard acid to give end-point with methyl orange or erthyrosine, and P equals volume of acid to give end-point with phenolphthalein.

I. $P=0$. The water contains no carbonates or hydroxides and ME equals the bicarbonates.

II. P is less than half ME; the water contains carbonates and bicarbonates.

$$\text{Carbonates} = 2 P.$$

$$\text{Bicarbonates} = \text{ME} - 2 P.$$

III. P is more than half ME; the water contains carbonates and hydroxides.

$$\text{Carbonates} = 2 (\text{ME} - P).$$

$$\text{Hydroxides} = 2 P - \text{ME}.$$

IV. P is equal to half ME; the water contains carbonates alone.

$$\text{Carbonates} = \text{ME} \text{ or } 2 P.$$

V. P is equal to ME; the water contains hydroxides alone.

$$\text{Hydroxides} = P \text{ or ME}.$$

170. If an attempt were made to prepare a mixture of bicarbonates and hydroxides the two would react with the consequent production of carbonate alone or of carbonate with bicarbonate or hydroxide, depending upon the relative amounts originally used. The titration of such a mixture would therefore fall under one of the five cases above.

171. It need hardly be mentioned that when sodium carbonate is present in a water, calcium and magnesium salts will be absent or low in amount.

Determination of Iron

172. **Solutions.**—(1) Standard iron solution. This is made by dissolving 0.700 g. of clear crystals of ferrous ammonium sulfate in 80 cc. of a mixture of equal volumes of water and concentrated sulfuric acid, just previously prepared so that the solution will be hot. Potassium permanganate is then added till a permanent pink color shows the oxidation of all of the iron, after which the solution is diluted to one liter. Sometimes on standing a turbidity appears due to the hydrolytic precipitation of the iron. If this happens, a fresh solution should be made, using more sulfuric acid. One cubic centimeter of this solution = 0.1 mg. Fe.

(2) Potassium sulfocyanate solution. Twenty grams of the salt is dissolved in one liter of water.

(3) Potassium permanganate solution. Approximately 0.2N is convenient.

(4) Hydrochloric acid. The concentrated acid, sp. gr. 1.2, should be used. It must be free from iron.

173. **Procedure.**—Fifty cubic centimeters of the water is evaporated to dryness and the residue gently ignited in order to destroy organic matter. (The residue from the determination of total solids may be used.) The iron compounds in this residue are then dissolved by adding about 5 cc. of concentrated hydrochloric acid and warming the dish which should be so turned and inclined as to cause the hot acid to reach every part of the interior. A few cubic centimeters of water is next added and the contents of the dish washed into a 100 cc. Nessler tube. If the solution is turbid it must be filtered. Finally, in order to insure the complete oxidation of the iron, potassium permanganate solution is added till a pink color that will remain at least five minutes is produced. The tube is then set aside till the standards are prepared.

174. Standards for the color comparison are made by measuring from 0.05 to 4.00 cc. of standard iron solution into a series of 100 cc. Nessler tubes. Each portion is diluted to about 50 cc. and 5 cc. of concentrated hydrochloric acid added. Enough potassium permanganate solution is next put in to produce a permanent pink color.

175. When the tube containing the iron from the water sample and those containing the standard iron have been brought to the final treatment with permanganate, 10 cc. of potassium sulfocyanate solution is added to each one. This destroys the pink color of the permanganic acid and develops a red color due to the formation of ferric sulfocyanate. Comparisons with the standards should be made at once because the red color is not permanent, especially in strong light.

176. Since the color of ferric sulfocyanate is not materially affected by the order in which the reagents are mixed, standard tubes of different depths of color may be made by starting with one containing a small amount of iron solution and then, as needed, adding successive, measured portions until a color is reached that matches that of the tube containing the iron from the sample of water.

177. The number of cubic centimeters of standard iron solution required to match the iron from 50 cc. of water when multiplied by 2 = parts per million of Fe.

Determination of Chloride

178. **Solutions.**—(1) Standard silver nitrate solution. Clear crystals of pure silver nitrate are dissolved in water at the rate of 4.791 g. per liter. One cubic centimeter of this solution = 0.001 g. Cl.

(2) Standard sodium chloride solution. This is prepared from

pure fused sodium chloride of which 1.648 g. is dissolved in water and diluted to one liter. One cubic centimeter = 0.001 g. Cl.

(3) Indicator, potassium chromate solution. About 50 g. of yellow potassium chromate (K_2CrO_4) is dissolved in 100 cc. of water and any chlorides present are precipitated by the slow addition of silver nitrate solution till a permanent red precipitate of silver chromate forms. The solution is then filtered and diluted to a liter.

179. **Procedure.**—Fifty cubic centimeters (180) of the water is titrated in a porcelain dish with the standard silver nitrate solution with about 1 cc. of the potassium chromate solution as indicator. The end-point is the first appearance of a permanent red tinge due to the formation of silver chromate which takes place as soon as all of the chlorides have been precipitated as silver chloride. The volume of silver nitrate solution required to give this end-point will, however, be somewhat more than the equivalent of the chloride in the water and therefore a correction (182) must be found as follows: Having noted the volume of silver nitrate solution required for the titration of 50 cc. of the water, the same volume of standard sodium chloride solution is measured into a dish and diluted with water to 50 cc. Chromate indicator is next added and the solution titrated with standard silver nitrate. The volume of silver nitrate solution required for this titration of the salt will be greater than that used for the sample of water. The difference between the two volumes is the correction and it is to be subtracted from the volume used in titrating the water. The remainder is the volume of silver nitrate solution equivalent to the chloride in the water. The number of cubic centimeters so found when multiplied by 20 = parts per million of Cl.

Notes

180. The procedure as outlined above must of course be modified to suit certain conditions. (a) If there is enough chloride in the water to require more than 4 or 5 cc. of silver nitrate solution less than 50 cc. of sample should be used. In such an event the standard sodium chloride solution used for determining the correction should then be diluted to the same volume. (b) If the chloride in the water is very small in amount, a cubic centimeter of standard salt solution should be added to the sample before titration and appropriate correction made for the addition. (c) In case the water is acid, sodium carbonate should be added till just alkaline to phenolphthalein, the red color of which is then just discharged with dilute sulfuric acid. (d) Waters that are sufficiently alkaline to redden phenolphthalein should be treated with dilute sulfuric acid as described in (c) above. (e) Colored waters must be boiled with a little precipitated and washed aluminium hydroxide and filtered, due correction being made for the change in volume. (f) Sulfides if present would interfere with the titration by forming black silver sulfide. In Ohio waters sulfides consist of hydrogen sulfide which oxidizes so rapidly that no trouble was experienced after the samples had been exposed some time to the air.

181. At best the silver chromate end-point is difficult to recognize till practice has developed skill. The inexperienced will do well therefore to have at hand a comparison dish containing chromate and some silver chloride. A partially titrated

sample is excellent for such use. Working in yellow light such as given by a luminous gas flame or a carbon electric light bulb is also a great help.

182. The silver chloride formed during the course of a water titration is a white solid and therefore tends to mask the red color of the silver chromate upon the formation of which in visible amount the end-point depends. This masking effect is of course greater the larger the amount of silver chloride and consequently in the case of a water of high chloride content relatively more silver nitrate solution must be added to produce enough of the red silver chromate to show. The error will in other words vary with the amount of chloride in the water and must therefore be determined for different amounts.

183. In the procedure above, this error is determined by titrating an amount of chloride approximately the same as that in the water and under the same conditions of concentration, amount of indicator, etc., as used for the sample of water. Since the standard solutions of sodium chloride and silver nitrate are separately prepared and both equivalent to the same amount of chloride, the difference in volume between a given portion of the chloride solution and that of the silver solution required to titrate it is the correction to apply for the conditions of that titration. The value of the correction will remain constant for all amounts of salt solution within a few tenths of a cubic centimeter of the amount actually titrated and therefore no error is introduced by determining it with the use of chloride solution slightly stronger than that of the sample of water. Where many titrations are to be made the corrections should be determined once for all and tabulated or plotted as a curve. If only an occasional titration is made it is best to follow the procedure in 179 on account of the difficulties of the end-point.²⁴

184. Another general method for eliminating the end-point errors of this titration is to determine the standard of the silver nitrate solution by titrating it against a known amount of pure sodium chloride. If this plan is followed it will then be necessary always to have the conditions of an analysis like those of the standardization, that is, the volume of water used and the amount of chloride present must be the same. The necessary dilution and concentration is as a rule more trouble than the procedure given above.

Determination of Total Solids

185. **Procedure.**—Fifty cubic centimeters of water (186) is evaporated in a platinum or porcelain dish to dryness on the water bath. After weighing, the dish and contents are again heated on the bath and reweighed to insure completeness of drying. The weight in milligrams of the residue so obtained multiplied by 20 = parts per million.

Notes

186. Many Ohio waters are turbid and therefore the question will arise as to whether they should be filtered. The answer to this question depends upon the information sought. If the dissolved total solids are wanted the water must obviously be filtered, but if total solids including suspended matter is required, the sample portion must be taken so that the undissolved solids will represent an average of the whole.

In the work of the Survey the undissolved matter was included. If the turbidity was of a sort that remained suspended for a long time, the large sample was merely shaken and the portion for the total solids determination poured out. In case the suspended matter settled rather rapidly, a current of air was bubbled through the

²⁴A full discussion of the errors incident to this method for the determination of chlorides is given by Hazen in the American Chemical Journal for 1889, page 409.

water in the large sample bottle and while this was being done the portion for total solids was siphoned from about the middle.

187. The above method is an easy and rapid one for making a determination of total solids. It does not, however, take into account any loss of acid due to hydrolysis nor can it be said that the final drying on the water bath will give as concordant results as heating at about 103° as recommended by Standard Methods. The interpretative value of the results is, however, so little that extra precautions are hardly worth the time to apply them.

Determination of Nitrate

188. **Solutions.**—(1) Standard potassium nitrate solution. A stock solution is first made by dissolving carefully selected, clear crystals of potassium nitrate at the rate of 2.04 g. per liter. The final standard solution employed in the analysis is then prepared by evaporating 10 cc. of the stock solution just to dryness (191) on the water bath and treating the residue so obtained as follows: Six cubic centimeters of the phenolsulfuric acid is dropped rapidly onto the residue so that it will be equally distributed over the surface. Residue and acid are then quickly rubbed together by means of a thick stirring rod bent slightly at the end to correspond with the curvature of the dish. The mixture is then diluted to one liter. One cubic centimeter = 0.5 mg. NO_3 .

(2) Phenolsulfuric acid. For the preparation of 200 cc. of this reagent 30 g. of synthetic phenol is mixed with 370 g. of pure, concentrated sulfuric acid in a flask and the whole is heated for six hours in boiling water. The flask, which should be loosely stoppered, must be supported so that all but the neck is completely immersed in the water.

189. **Procedure.**—Twenty-five cubic centimeters of water is evaporated in a small porcelain dish on the water bath till all but the last drop of liquid has disappeared (191). The dish is then removed and the rest of the liquid allowed to evaporate from the heat yet remaining. The residue is next treated with phenolsulfuric acid by dropping 1 cc. of this reagent over the surface and quickly rubbing it in with a bent stirring rod. Twenty-five cubic centimeters of distilled water is then added and sufficient ammonium hydroxide to make the mixture alkaline. It is best to determine experimentally once for all the volume of ammonia necessary to neutralize the acid and provide a slight excess, and then always add this measured amount. If nitrates are present a yellow color proportional in depth to the amount of nitrate will be produced. Comparison with standards is carried out as follows:

190. An approximate amount of standard potassium nitrate solution is measured into a dish similar to the one used for the water and the volume made up to 25 cc. with distilled water. A volume of ammonium hydroxide equal to that used with the sample of water is next added so that the volumes of liquid in the two dishes will be the

same. The color comparison can now be made. If the portion of standard nitrate solution does not produce the right depth of color to match that of the sample another portion must be tried till the proper amount is found. Since the colors are permanent for a long time, this method of cut and try is shorter than the preparation of a long series of standards. The latter plan would, however, be preferable if a large number of nitrate determinations were made at a time. The number of cubic centimeters of standard nitrate solution required to match the color produced by 25 cc. of water, divided by 2 = parts per million of NO_3 .

Notes

191. There may be considerable loss of NO_3 if the residue from evaporation is left for some time on the water bath.

192. Chlorides if present in amounts greater than 30 parts per million interfere with this method for the determination of nitrates. They can be removed or reduced below 30 parts by precipitation with silver sulfate solution, proper correction being made for change in volume due to the addition of the silver solution. In the work of the Survey, however, this was not done, because the change in the results was not deemed sufficient to affect the general opinion of the water.

Determination of Sodium and Silica

193. There is no volumetric method for the determinations of sodium, potassium, and silica in a water, but when the other constituents have been determined, a fair idea of the amounts of these can be found by difference. It is necessary, however, in applying this procedure to transform the total solids into more definite compounds than those obtained by simple evaporation of the water. This is readily accomplished by treating the residue with sulfuric acid, evaporating the excess and finally igniting the remaining sulfates at a low red heat. By this procedure the sodium, potassium, calcium, and magnesium salts are transformed into sulfates and the iron into oxide. The silica remains unchanged and may now be determined from the loss in weight on treatment with hydrofluoric acid. The sodium may then be found by subtracting the sum of the calcium and magnesium sulfates and the iron oxides, all calculated from the results of previous determinations. Since potassium as a rule is present in traces only, the difference is called sodium sulfate. The results obtained by this method can claim no high degree of accuracy but they serve at least to indicate the approximate amounts of silica and of the alkalis present.

194. **Procedure.**—The “total solids” residue (185) is treated with an excess of dilute sulfuric acid in the original dish, which for this purpose must be of platinum, and the dish is then set on a hot plate the temperature of which is so regulated that the excess of acid is driven off without loss by spattering. The residue obtained is finally ignited

over a free flame at a low red heat. To facilitate driving out the last traces of sulfuric acid a small piece of ammonium carbonate should be added. The dish is finally cooled in a desiccator and weighed, the residue being assumed to consist of $\text{CaSO}_4 + \text{MgSO}_4 + \text{Na}_2\text{SO}_4$ (K_2SO_4) $+ \text{Fe}_2\text{O}_3 + \text{SiO}_2$.

195. Determination of silica. If silica is to be determined the residue as obtained above is next treated with about 1 cc. of hydrofluoric acid and a drop or two of sulfuric acid and the mixture is again evaporated on the hot plate and finally ignited at a low red heat, cooled, and weighed. The loss in weight is silica (SiO_2).

196. Determination of sodium. (a) If silica has been determined, the residue remaining in the dish will consist of $\text{CaSO}_4 + \text{MgSO}_4 + \text{Na}_2\text{SO}_4 + \text{Fe}_2\text{O}_3$. To obtain the weight of the Na_2SO_4 it is necessary only to calculate from previous determinations the amounts of CaSO_4 , MgSO_4 , and Fe_2O_3 and subtract their sum from the weight of the residue.

197. (b) If silica is not to be determined, hydrofluoric acid may be used with the sulfuric in the first treatment of the total solids residue and the silica driven out at the same time that the metals are transformed into sulfates. The subsequent calculations are the same as those described above. The weight of sodium sulfate corresponding to the sodium salts originally in the volume of water evaporated can be found by either method and may be calculated then as parts per million in any form of combination desired. Table XV will be found useful in making the calculations required in the determinations of silica and sodium.

TABLE XV

Conversion table for use with chemical methods of this Bulletin²⁵

1	2	3	4	5	6	7	8
CaCO_3	Mg	Ca	CaSO_4	MgSO_4	Na_2SO_4 to Na	Fe	Fe_2O_3
1	0.2	0.4	1.4	1.2	0.3	0.1	0.14
2	0.5	0.8	2.7	2.4	0.7	0.2	0.28
3	0.7	1.2	4.1	3.6	1.0	0.3	0.43
4	1.0	1.6	5.4	4.8	1.3	0.4	0.57
5	1.2	2.0	6.8	6.0	1.6	0.5	0.72
6	1.5	2.4	8.2	7.2	1.9	0.6	0.86
7	1.7	2.8	9.5	8.4	2.3	0.7	1.00
8	1.9	3.2	10.9	9.6	2.6	0.8	1.14
9	2.2	3.6	12.2	10.8	2.9	0.9	1.28
10	2.4	4.0	13.6	12.0	3.2	1.0	1.43
11	2.7	4.4	15.0	13.2	3.6	1.2	1.72
12	2.9	4.8	16.3	14.4	3.9	1.4	2.00
13	3.2	5.2	17.7	15.6	4.2	1.6	2.29
14	3.4	5.6	19.0	16.8	4.5	1.8	2.6

²⁵Compiled by C. R. DeLong.

TABLE XV—Continued

1	2	3	4	5	6	7	8
CaCO ₃	Mg	Ca	CaSO ₄	MgSO ₄	Na ₂ SO ₄ to Na	Fe	Fe ₂ O ₃
15	3.6	6.0	20.4	18.0	4.9	2.0	2.9
16	3.9	6.4	21.7	19.2	5.2	2.2	3.1
17	4.1	6.8	23.1	20.4	5.5	2.4	3.4
18	4.4	7.2	24.5	21.6	5.8	2.6	3.7
19	4.6	7.6	25.8	22.8	6.2	2.8	4.0
20	4.9	8.0	27.2	24.0	6.5	3.0	4.3
21	5.1	8.4	28.6	25.2	6.8	3.2	4.6
22	5.3	8.8	29.9	26.4	7.1	3.4	4.9
23	5.6	9.2	31.3	27.6	7.5	3.6	5.2
24	5.8	9.6	32.6	28.8	7.8	3.8	5.4
25	6.1	10.0	34.0	30.0	8.1	4.0	5.7
26	6.3	10.4	35.3	31.2	8.4	4.2	6.0
27	6.6	10.8	36.7	32.4	8.8	4.4	6.3
28	6.8	11.2	38.1	33.6	9.1	4.6	6.6
29	7.1	11.6	39.4	34.8	9.4	4.8	6.9
30	7.3	12.0	40.8	36.0	9.7	5.0	7.2
31	7.5	12.4	42.2	37.2	10.0	5.2	7.4
32	7.8	12.8	43.5	38.4	10.4	5.4	7.7
33	8.0	13.2	44.9	39.6	10.7	5.6	8.0
34	8.3	13.6	46.3	40.8	11.0	5.8	8.3
35	8.5	14.0	47.6	42.0	11.3	6.0	8.6
36	8.8	14.4	49.0	43.2	11.6	6.4	9.2
37	9.0	14.8	50.3	44.4	12.0	6.6	9.4
38	9.2	15.2	51.7	45.6	12.3	6.8	9.7
39	9.5	15.6	53.0	46.8	12.6	7.0	10.0
40	9.7	16.0	54.4	48.0	12.9	7.2	10.3
41	10.0	16.4	55.8	49.2	13.3	7.4	10.6
42	10.2	16.8	57.1	50.4	13.6	7.6	10.9
43	10.5	17.2	58.5	51.6	14.0	7.8	11.1
44	10.7	17.6	59.8	52.8	14.3	8.0	11.4
45	10.9	18.0	61.2	54.0	14.6	8.2	11.7
46	11.2	18.4	62.6	55.2	14.9	8.4	12.0
47	11.4	18.8	63.9	56.4	15.3	8.6	12.3
48	11.7	19.2	65.3	57.6	15.6	8.8	12.6
49	11.9	19.6	66.6	58.8	15.9	9.0	12.9
50	12.2	20.0	68.0	60.0	16.2	.....	.....
51	12.4	20.4	69.4	61.2	16.5	9.2	13.2
52	12.6	20.8	70.7	62.4	16.9	9.4	13.4
53	12.9	21.2	72.1	63.6	17.2	9.6	13.7
54	13.1	21.6	73.4	64.8	17.5	9.8	14.0
55	13.4	22.0	74.8	66.0	17.8	10.0	14.3
56	13.6	22.4	76.2	67.2	18.1	11	15.7
57	13.9	22.8	77.5	68.4	18.5	12	17.2
58	14.1	23.2	78.9	69.6	18.8	13	18.6
59	14.4	23.6	80.2	70.8	19.1	14	20.0
60	14.6	24.0	81.6	72.0	19.4	15	21.4
61	14.8	24.4	83.0	73.2	19.7	16	22.8
62	15.1	24.8	84.3	74.4	20.1	17	24.3

TABLE XV—Concluded

1	2	3	4	5	6	7	8
CaCO_3	Mg	Ca	CaSO_4	MgSO_4	Na_2SO_4 to Na	Fe	Fe_2O_3
63	15.3	25.2	85.7	75.6	20.4	18	25.7
64	15.6	25.6	87.0	76.8	20.7	19	27.2
65	15.8	26.0	88.4	78.0	21.0	20	28.6
66	16.1	26.4	89.8	79.2	21.3	21	30.0
67	16.3	26.8	91.1	80.4	21.7	22	31.5
68	16.5	27.2	92.5	81.6	22.0	23	32.9
69	16.8	27.6	93.8	82.8	22.3	24	34.4
70	17.0	28.0	95.2	84.0	22.7	25	35.8
71	17.3	28.4	96.6	85.2	23.0	26	37.2
72	17.5	28.8	97.9	86.4	23.4	27	38.6
73	17.8	29.2	99.3	87.6	23.7	28	40.0
74	18.0	29.6	100.6	88.8	24.0	29	41.5
75	18.2	30.0	102.0	90.0	24.3	30	42.9
76	18.5	30.4	103.4	91.2	24.7	31	44.3
77	18.7	30.8	104.7	92.4	25.0	32	45.8
78	19.0	31.2	106.1	93.6	25.3	33	47.2
79	19.2	31.6	107.4	94.8	25.6	34	48.7
80	19.5	32.0	108.8	96.0	25.9	35	50.0
81	19.7	32.4	110.2	97.2	26.2	36	51.5
82	19.9	32.8	111.5	98.4	26.6	37	52.9
83	20.2	33.2	112.9	99.6	26.9	38	54.4
84	20.4	33.6	114.2	100.8	27.2	39	55.8
85	20.7	34.0	115.6	102.0	27.5	40	57.2
86	20.9	34.4	117.0	103.2	27.9	41	58.6
87	21.2	34.8	118.3	104.4	28.2	....	....
88	21.4	35.2	119.7	105.6	28.5	....	....
89	21.6	35.6	121.0	106.8	28.9	....	....
90	21.9	36.0	122.4	108.0	29.2	....	....
91	22.1	36.4	123.8	109.2	29.5	....	....
92	22.4	36.8	125.1	110.4	29.9	....	....
93	22.6	37.2	126.5	111.6	30.2	....	....
94	22.9	37.6	127.8	112.8	30.5	....	....
95	23.1	38.0	129.2	114.0	30.8	....	....
96	23.4	38.4	130.6	115.2	31.2	....	....
97	23.6	38.8	131.9	116.4	31.5	....	....
98	23.8	39.2	133.3	117.6	31.8	....	....
99	24.1	39.6	134.6	118.8	32.1	....	....
100	24.3	40.0	136.0	120.0	32.4	....	....

Explanation of Table XV

Column 1 gives parts by weight of CaCO_3 and Columns 2, 3, 4, and 5 give the equivalent parts by weight of Mg, Ca, CaSO_4 , and MgSO_4 . Example: If in the determination of Mg the result is obtained in equivalent parts of CaCO_3 and it is then wished to obtain the p.p.m. of Mg, Column 2 gives the desired value at once. Similarly, for the determination of Na according to 196, the amounts of MgSO_4 and CaSO_4 can be obtained at once from the values of Mg and Ca previously determined.

Column 6 gives the amount of Na corresponding to the numbers in Column 1 read as Na_2SO_4 . Example: If by the method of 196 it is found that there are 35 mg. of Na_2SO_4 in the residue, Column 6 shows at once that the corresponding weight of Na is 11.3 mg.

Column 7 gives parts by weight of Fe and Column 8 the corresponding amount of Fe_2O_3 . These two columns are also used in making the calculations for the determinations of Na and SiO_2 .

Note.—Column 5 can also be read as the weights of SO_4 equivalent to the numbers in Column 1 considered as SO_3 . This is because the factor 1.2030 for converting CaCO_3 into equivalent parts of MgSO_4 is practically the same as the factor for converting SO_3 into equivalent parts of SO_4 which is 1.1999. No error will therefore be introduced by reading Column 5 as SO_4 equivalent to SO_3 as of Column 1.

Determination of Sulfate

198. (a) Gravimetric method. The most accurate method for the determination of sulfates in a water is by precipitation with barium chloride and weighing the resulting barium sulfate. The author's plan is to add about 1 cc. of strong hydrochloric acid to 500 cc. of the water and filter if the liquid is not clear. The mixture is next heated to boiling and ten per cent barium chloride solution added drop by drop with constant stirring till no further formation of precipitate can be observed on adding another drop, after waiting for the supernatant liquid to clear somewhat. When this point is reached about one-half more than the amount of barium chloride solution already used is added and the vessel set aside for an hour or longer before filtering. The precipitate is finally filtered, washed with hot water till free from chlorides, and ignited as barium sulfate. The weight in milligrams of the precipitate so obtained when multiplied by 0.823 gives the parts per million of SO_4 .

199. (b) Turbidimetric method. The gravimetric method is slow and accordingly the Survey used the more rapid turbidimetric procedure which consists in precipitating the sulfate ion with barium chloride and measuring the resulting cloudiness in a Jackson turbidimeter according to Muer.²⁶

200. **Procedure.**—One hundred cubic centimeters of the water is treated in a small bottle with 1 cc. (206) of hydrochloric acid, 1 to 1, and a barium chloride tablet added (203). The bottle is then stoppered and slowly inverted and righted till the tablet dissolves. When this has taken place it may be assumed that the precipitation of the barium sulfate is complete. Violent shaking must be avoided, because for turbidimetric measuring a precipitate should be as finely divided as possible. Shaking has a tendency to increase the size of the particles. The measurement of the turbidity should be made at once, for which purpose the candle (202) is lighted and the instrument set where the flame is protected from drafts. A few cubic centimeters of the turbid

²⁶J. Ind. and Eng. Chem. 3, 553.

liquid from the bottle is next poured into the observation tube which is then put into its support over the candle. More liquid is added in small portions at a time till, on looking down through the tube with the eye about half an inch from the top, the image of the flame is no longer visible. The depth of the column of turbid liquid so obtained is then noted (205) and by reference to Table XVI the amount of sulfate corresponding to this depth is found. Weight of SO_4 is found by multiplying the values in the SO_3 column by 1.200. Having made one reading as described above, it is well to empty the observation tube into the bottle and make another test.

Notes

201. Accurate measurements with the candle turbidimeter demand experience and attention to numerous details. Those who are proposing to use this method will find Muer's article most helpful.

202. Some recommend the expensive standard candles and these were actually used in the work of the Survey. It is doubtful, however, if this is necessary since Muer has shown that the character of the flame has little effect on the results.

203. Solid barium chloride must be used in precipitating barium sulfate for turbidimetric measurement because it produces a very finely divided precipitate. Muer studied this point in detail and found not only that solid salt was necessary for the best results but that the size of the barium chloride crystals used had a pronounced effect in the sense that the larger crystals produced the more finely divided precipitate. Since the turbidity or power to obscure the flame is greatly increased by increasing the fineness of the precipitate particles it can readily be seen that this would have the same effect as a larger amount of sulfate and would thus lead to high results. Muer found that very coarse crystals of barium chloride gave a turbidity with a given concentration of sulfate more than twice as great as that produced by very fine crystals. In order to reduce this effect as much as possible, he recommends the use of tablets²⁷ of compressed barium chloride.

204. Muer explains the action of large sized particles of barium chloride by ascribing it to the slower rate of precipitation resulting from their use. The author is, however, inclined to the opposite view. It is a general rule that the more rapidly a precipitate forms, the more finely divided it will be and therefore conditions that increase the rate of precipitation also increase the fineness of the precipitate particles. In the case of the solid barium chloride used as a precipitant for sulfates it would appear that a film of saturated solution forms on the surface of the crystals and that precipitation takes place in this film. This precipitation is very rapid because of the high concentration of the barium chloride at that point and therefore the particles of barium sulfate are very small. The apparent slow precipitation is due entirely to the slow rate at which the solution carrying the sulfate ions comes into contact with the barium chloride crystals. With very small crystals of barium chloride the surface would be greatly increased and more barium ions would escape into the solution where precipitation would then go on slower with the consequent formation of larger particles of barium sulfate.

205. The Jackson turbidimeter is equipped with tubes with millimeter scales etched on the sides. This makes the reading of the depth of liquid very convenient. Such tubes, however, are expensive and may be replaced by a 100 cc. Nessler tube

²⁷The tablets used by the Survey were obtained from the Fraser Tablet Co.

in which the depth of liquid can be measured by means of an ordinary millimeter scale.

206. In using the turbidimetric method in the work of the Survey a slight error was made and remained undetected till after the laboratory was dismantled. Muer's table is arranged on the basis of 100 cc. as the volume to which the turbidities are referred. Since the Survey's procedure was to start with 100 cc. of water and add 1 cc. of dilute hydrochloric acid before precipitating the barium sulfate, the turbidity was produced in a volume of 101 cc. and therefore all results so obtained are 1 per cent low. This is, however, entirely negligible and in the upper ranges of the table within the error of reading. Accordingly the results have not been recalculated.

TABLE XVI

Data for use with Jackson's candle turbidimeter. Sulphur and SO_3 contained in 100 cc. precipitated.

(Muer, J. Ind. and Eng. Chem. 3, 555)

Depth Cm.	S Mg.	SO_3 Mg.	Depth Cm.	S Mg.	SO_3 Mg.	Depth Cm.	S Mg.	SO_3 Mg.
1.0	20.0	50.0	4.2	4.24	10.75	7.4	2.67	6.68
1.1	18.0	45.0	4.3	4.16	10.50	7.5	2.64	6.60
1.2	16.5	41.3	4.4	4.08	10.25	7.6	2.61	6.53
1.3	15.0	37.5	4.5	4.00	10.00	7.7	2.59	6.48
1.4	13.5	33.8	4.6	3.93	9.83	7.8	2.56	6.40
1.5	12.5	31.3	4.7	3.86	9.65	7.9	2.54	6.35
1.6	11.2	28.0	4.8	3.79	9.48	8.0	2.51	6.28
1.7	10.0	25.0	4.9	3.72	9.30	8.1	2.49	6.23
1.8	9.5	23.8	5.0	3.66	9.15	8.2	2.47	6.18
1.9	9.0	22.5	5.1	3.60	9.00	8.3	2.44	6.10
2.0	8.5	21.3	5.2	3.54	8.85	8.4	2.42	6.05
2.1	8.0	20.0	5.3	3.49	8.73	8.5	2.40	6.00
2.2	7.6	19.0	5.4	3.43	8.58	8.6	2.38	5.95
2.3	7.3	18.3	5.5	3.38	8.45	8.7	2.36	5.90
2.4	7.0	17.5	5.6	3.33	8.33	8.8	2.34	5.85
2.5	6.7	16.8	5.7	3.28	8.20	8.9	2.32	5.80
2.6	6.5	16.3	5.8	3.24	8.10	9.0	2.30	5.75
2.7	6.3	15.8	5.9	3.20	8.00	9.1	2.28	5.70
2.8	6.1	15.3	6.0	3.15	7.88	9.2	2.26	5.65
2.9	5.9	14.8	6.1	3.11	7.78	9.3	2.25	5.63
3.0	5.7	14.3	6.2	3.07	7.68	9.4	2.23	5.58
3.1	5.5	13.8	6.3	3.03	7.58	9.5	2.21	5.53
3.2	5.4	13.5	6.4	2.99	7.48	9.6	2.19	5.48
3.3	5.2	13.0	6.5	2.95	7.38	9.7	2.18	5.45
3.4	5.1	12.8	6.6	2.92	7.30	9.8	2.16	5.40
3.5	5.0	12.5	6.7	2.88	7.20	9.9	2.15	5.38
3.6	4.85	12.25	6.8	2.85	7.13	10.0	2.13	5.33
3.7	4.75	12.00	6.9	2.82	7.05	10.1	2.11	5.28
3.8	4.63	11.75	7.0	2.79	6.98	10.2	2.10	5.25
3.9	4.52	11.50	7.1	2.76	6.90	10.3	2.09	5.23
4.0	4.43	11.25	7.2	2.73	6.83	10.4	2.07	5.18
4.1	4.33	11.00	7.3	2.70	6.75	10.5	2.06	5.15

TABLE XVI—Concluded

Depth Cm.	S Mg.	SO ₂ Mg.	Depth Cm.	S Mg.	SO ₂ Mg.	Depth Cm.	S Mg.	SO ₂ Mg.
10.6	2.04	5.10	15.4	1.59	3.98	20.2	1.30	3.25
10.7	2.03	5.08	15.5	1.59	3.98	20.3	1.29	3.23
10.8	2.02	5.05	15.6	1.58	3.95	20.4	1.28	3.20
10.9	2.01	5.03	15.7	1.57	3.93	20.5	1.28	3.20
11.0	2.00	5.00	15.8	1.57	3.93	20.6	1.27	3.18
11.1	1.98	4.95	15.9	1.56	3.90	20.7	1.26	3.15
11.2	1.97	4.93	16.0	1.56	3.90	20.8	1.26	3.15
11.3	1.95	4.88	16.1	1.55	3.88	20.9	1.25	3.13
11.4	1.94	4.85	16.2	1.54	3.85	21.0	1.25	3.13
11.5	1.93	4.83	16.3	1.54	3.85	21.1	1.24	3.10
11.6	1.92	4.80	16.4	1.53	3.83	21.2	1.23	3.08
11.7	1.91	4.78	16.5	1.53	3.83	21.3	1.23	3.08
11.8	1.90	4.75	16.6	1.52	3.80	21.4	1.22	3.05
11.9	1.89	4.73	16.7	1.52	3.80	21.5	1.21	3.03
12.0	1.88	4.70	16.8	1.51	3.78	21.6	1.21	3.03
12.1	1.87	4.68	16.9	1.50	3.75	21.7	1.20	3.00
12.2	1.86	4.65	17.0	1.50	3.75	21.8	1.20	3.00
12.3	1.85	4.63	17.1	1.49	3.73	21.9	1.19	2.98
12.4	1.84	4.60	17.2	1.49	3.73	22.0	1.18	2.95
12.5	1.83	4.58	17.3	1.48	3.70	22.1	1.18	2.95
12.6	1.82	4.55	17.4	1.47	3.68	22.2	1.17	2.93
12.7	1.81	4.53	17.5	1.47	3.68	22.3	1.16	2.90
12.8	1.80	4.50	17.6	1.46	3.65	22.4	1.16	2.90
12.9	1.79	4.48	17.7	1.45	3.63	22.5	1.15	2.88
13.0	1.78	4.45	17.8	1.44	3.60	22.6	1.15	2.88
13.1	1.77	4.43	17.9	1.44	3.60	22.7	1.14	2.85
13.2	1.76	4.40	18.0	1.43	3.58	22.8	1.13	2.83
13.3	1.75	4.38	18.1	1.43	3.58	22.9	1.13	2.83
13.4	1.74	4.35	18.2	1.42	3.55	23.0	1.12	2.80
13.5	1.73	4.33	18.3	1.41	3.53	23.1	1.11	2.78
13.6	1.73	4.33	18.4	1.41	3.53	23.2	1.11	2.78
13.7	1.72	4.30	18.5	1.40	3.50	23.3	1.10	2.75
13.8	1.71	4.28	18.6	1.40	3.50	23.4	1.09	2.73
13.9	1.70	4.25	18.7	1.39	3.48	23.5	1.08	2.70
14.0	1.70	4.25	18.8	1.38	3.45	23.6	1.08	2.70
14.1	1.69	4.23	18.9	1.38	3.45	23.7	1.07	2.68
14.2	1.68	4.20	19.0	1.37	3.43	23.8	1.06	2.65
14.3	1.67	4.18	19.1	1.37	3.43	23.9	1.05	2.63
14.4	1.66	4.15	19.2	1.36	3.40	24.0	1.05	2.63
14.5	1.66	4.15	19.3	1.35	3.38	24.1	1.04	2.60
14.6	1.65	4.13	19.4	1.35	3.38	24.2	1.03	2.58
14.7	1.64	4.10	19.5	1.34	3.35	24.3	1.03	2.58
14.8	1.63	4.08	19.6	1.34	3.35	24.4	1.02	2.55
14.9	1.62	4.05	19.7	1.33	3.33	24.5	1.02	2.55
15.0	1.62	4.05	19.8	1.32	3.30	24.6	1.01	2.53
15.1	1.61	4.03	19.9	1.32	3.30	24.7	1.01	2.53
15.2	1.60	4.00	20.0	1.31	3.28	24.8	1.00	2.50
15.3	1.60	4.00	20.1	1.30	3.25	24.9	1.00	2.50
						25.0	1.00	2.50

CHAPTER VI

INTERPRETATION OF INDUSTRIAL WATER ANALYSIS

General Principles

207. Knowledge of water chemistry is not yet at such a stage of development that a routine procedure or a set of standards can be given according to which a person with little experience can foretell the exact behavior of a water by inspecting its analysis. Nevertheless an accurate quantitative prediction can be made of the action of most waters when used for certain purposes and an accurate qualitative prediction of their action under most conditions. For example, the behavior of a water towards soap can be told at once from the analysis and even the amount of soap that will be destroyed by the water can be calculated. In a qualitative way the formation of scale and sludge can also be predicted and in many cases an accurate estimate of the quantity of the deposits can be made. Foretelling the exact nature of a deposit from a water, however, requires experience and chemical sense, and these qualities must be brought more and more to bear upon an analysis to prophesy concerning its probable corrosive and foaming tendencies. Even on these points, however, the analysis of some waters can be interpreted by the merest beginners. For example, the author's first consulting job was to decide whether a given mine water was the cause of a severe corrosion of the pumps. Since the water instantly turned blue litmus paper red it was fairly easy to decide.

208. In the following paragraphs some of the fundamental principles of interpretation will be given. If followed, they will enable any one to judge something at least of the behavior of a water from its analysis. The discussions apply only to the uses designated and have special reference to the statement of analyses employed in this Bulletin. No application to the medicinal qualities of water or to its wholesomeness for drinking is intended. It is assumed also that the reader is familiar with the chapters VIII, IX, and X.

Household Use

209. The objectionable qualities of a water for general household use are turbidity, sediment, odor, color, hardness, and iron. The higher the value of these characteristics the worse is the water. A hardness of 100 parts per million is about the upper limit of tolerance. Above that value the use of the water with soap becomes objectionable. Iron should be lower than 0.5 part per million or brown spots will appear on laundered clothes and bath room and kitchen equipment will be stained where the water drips on it.

Commercial Laundries

210. The quality of the water should be the same as that for household use. Iron ought to be absent or at least not more than 0.1 p. p. m. Excellent work can be done with water of 100 parts hardness but there will of course be a considerable waste of soap. This soap consumption can be calculated with the equation in paragraph 270. Large laundries will soften or treat the water and therefore the distribution of the total hardness between the carbonate and non-carbonate forms determines in no small degree the value of the water because it is much less costly to remove the carbonate hardness than the non-carbonate kind.

Scale Formation

211. In a general way the scaling tendency of a water is proportional to the hardness, but the following considerations must be kept in mind. Temporary or carbonate hardness causes soft, non-adhering sludge and permanent or non-carbonate hardness causes hard, strongly adhering scale. If the hard, adhering type of scale is large in amount it will under certain conditions entangle and cement into its structure some of the carbonates which would otherwise deposit as loose mud. Some waters may then deposit hard scale out of proportion to the permanent hardness. It is reasonable to suppose that the opposite effect may also take place, namely, that in the presence of much temporary hardness the deposited carbonates may at times be more than the hard scale ingredients can cement together and the scale though adhering will be soft and easy to remove. The character of the scale will therefore vary according to the relative amounts of the carbonate, sulfate, and calcium ions. In this connection, however, paragraph 285 should be read.

Corrosion

212. Corrosion is exceedingly difficult to predict in the case of the hard waters of Ohio because they form protective coatings of scale. Moderate scaling and corrosion may, however, go on simultaneously and the present state of our knowledge is not such as to afford rules for prediction. A soft or even a moderately hard water is fairly certain to be corrosive unless its dissolved oxygen has been removed. In all cases, however, the conditions under which a water is used must be considered. Many waters, for example, are non-corrosive in the cold but cause severe pitting in heating pipes and boiler tubes.

Foaming

213. A consideration of paragraphs 385 and 386 will indicate that the foaming tendencies of a boiler water are proportional to the sodium

salts with, however, the exception that foaming will not take place on account of the sodium salts alone. Finely divided solids must also be present.

The Stabler Equations

214. So far as the author is aware the only comprehensive scheme for interpreting an industrial water analysis is that of Stabler.²⁸ He, however, put all of his rules into mathematical form, and gave so little explanation of the philosophy of his plan and of the meanings of the terms in his equations that engineers and even many chemists have been slow to use his methods because they do not understand them. On the other hand, a few have perhaps gone to the opposite extreme and blindly use these equations in the belief that because they are in mathematical form they are expressions of absolutely correct scientific theories not included in other methods of interpretation. Both groups, it is believed, will be interested in the following presentation.

215. In the first place, it should be said that Stabler's plan is based on the same principles that underlie other plans. Soap-consuming power is computed on the amount of soap-destroying bases as shown by the analysis. The equations for calculating the amounts of lime and soda ash for softening a given water are the same as those given in another form in Chapter XI. The "foaming coefficient" is nothing more mysterious than the amount of sodium and potassium salts calculated from the amounts of sodium and potassium ions given in the analysis. The coefficient of corrosion is an effort to express the hydrogen ion concentration of the water when subjected to steam boiler conditions, and the scale formulas merely sum up the well-known scale-forming constituents of the water.

216. Stabler of course uses reacting values (53) in his equations, and employs coefficients that will give quantitative answers to such questions as (1) how much will the water foam in a steam boiler; (2) how much will it corrode; and (3) how much and what kind of scale will it deposit? In other words, the Stabler equations attempt to interpret the analysis.

217. In the following paragraphs the equations will be given with the numbers employed in Stabler's article in Water Supply Paper 274 of the U. S. Geological Survey. Detailed statements and explanations will be added for each equation and, as far as possible, the interpretative parts will be given in Stabler's own words.

Foaming

218. In the sections devoted to the discussion of foaming Stabler calls attention to the fact that among the substances which cause this

²⁸Eng. News 60, 355 (1908). Also U. S. Geol. Survey Water Supply Paper 274, p. 165 (1911).

trouble sodium and potassium salts greatly predominate. He therefore measures the tendency to foam in terms of these salts, and calls the parts per million present the "foaming coefficient" of the water. Since this at best is only an approximation nothing would be gained by accurately calculating the amount of sodium and potassium salts present and consequently the equation which is based on the ionic analysis uses a factor which gives the average of a mixture of chlorides, sulfates, and carbonates, the commonly occurring salts of sodium and potassium in water. The equation is as follows:

$$(8) \text{ Foaming coefficient } f = 62r\text{Na} + 78r\text{K} = 2.7\text{Na} + 2\text{K}.$$

219. Stabler uniformly gives two equations in one of which the reacting values—designated by r followed by the symbol of the ion—are employed and in the other the parts per million as shown in the analysis, designated by the symbol alone. For example, in the foaming equation above, the second part is read, $2.7 \times \text{p. p. m. of Na} + 2 \times \text{p. p. m. of K}$.

Notes

220. The factor 2.7 is the average of the three chemical factors, Na to NaCl, Na to Na_2SO_4 , and Na to Na_2CO_3 . The factor 2 is derived in the same way. The same results are obtained by multiplying the reacting values of the sodium and potassium by 62 and 78. These numbers are averages of the combination factors (88).

221. As in the last part of the equation, it would have been simpler and equally as good to have called the foaming coefficient the amount of sodium and potassium ions in the water. Such a value, however, would not have been comparable without calculation with the sodium and potassium salts as usually given in a water analysis. The value $2.7\text{Na} + 2\text{K}$ will be found very close to the sum of the salts and therefore is directly comparable with that sum.

222. Stabler does not consider the action of finely divided solid matter which seems to be a necessary factor in foaming (385 and 386). This, however, need not affect the validity of the equation because, in an Ohio boiler at any rate, the solid matter is always present and therefore the foaming will be proportional to the concentration of the alkali salts.

The following discussion which shows how to use the foaming coefficient in interpretation is quoted from Stabler's paper:

223. "The steam engineer is interested more in the number of hours his boiler may be run under ordinary load without danger of foaming than in the coefficient given above. This is really a combined index of priming and foaming, and may be calculated from the formula:

$$(8a) \text{ Run in hours: } Rh = \frac{a}{b} \left(\frac{c}{f} - 1 \right)$$

in which a = water capacity of boiler, b = hourly quantity of feed water used, f = foaming coefficient, and c is a constant which represents in parts per million the concentration of salts that will cause excessive foaming in the type of boiler under consideration.

224. "The usual remedy for foaming is blowing off a portion of the highly impure water and replacing it with fresh feed water. If a in the foregoing formula be made to represent the amount of water blown off at any time, the expression will indicate the length of time that may with safety elapse before blowing off again.

"The following approximate values have been determined for the constant c for various types of boilers and are here adapted from Christie's 'Boiler Waters.'

Locomotive boiler.....	2,500 to 3,500
Stirling boiler.....	4,000 to 5,000
Modern water-tube boiler (such as the Babcock & Wilcox or Heine).....	5,000 to 7,000
Horizontal return tubular boiler.....	8,000 to 10,000
Old-style two-flue boiler.....	17,000

225. "From these figures it appears that the locomotive boiler is the type most likely to give trouble on account of foaming and offers, therefore, a satisfactory basis for an arbitrary classification of waters according to their foaming tendency. A non-foaming water may be defined as one that can be used in a locomotive boiler throughout one week's work without foaming; a semi-foaming water as one that can not be used so long as a week, but one that will require one complete water change to avoid foaming in a locomotive boiler not oftener than every two days; and a foaming water as one that can not be used so long as two days in a locomotive boiler without blowing off or changing water to prevent foaming. Accepting these conditions, the following approximate classification of waters will result:

- (1) Nonfoaming: f not greater than 60.
- (2) Semifoaming: f greater than 60, but not greater than 200.
- (3) Foaming: f greater than 200."

Corrosion

226. The theory upon which the corrosion equation is built is purely that of the hydrogen ion concentration of the water in the boiler. The assumption is made that the dissolved gases in the water when it enters the boiler are driven out with the steam and no longer play a major role. Three hydrolytic reactions are given which produce hydrogen ions, namely,

- (1) $2Al + 3H_2O = Al_2O_3 + 6H$
- (2) $Fe + H_2O = FeO + 2H$
- (3) $Mg + H_2O = MgO + 2H$

and two reactions which cause the recombination of hydrogen ions, namely,

- (4) $H + HCO_3 = H_2O + CO_2$
- (5) $2H + CO_3 = H_2O + CO_2$

227. Reactions 4 and 5 counteract the effect of reactions 1, 2, and 3, and consequently the values for HCO_3 and CO_3 are subtracted in the equations below. The metals in reactions 1, 2, and 3 are ions. In a more familiar form, No. 3 for example would be written,



228. The "coefficient of corrosion," according to the Stabler equations below, is the net concentration of hydrogen ion in the water in the boiler. It is the sum of any hydrogen ion in the water plus that resulting from the hydrolysis of aluminium, iron, and magnesium salts minus that removed by carbonates and bicarbonates.

(9) Coefficient of corrosion, c .

$$c = 1.008 (r\text{H} + r\text{Al} + r\text{Fe} + r\text{Mg} - r\text{CO}_3 - r\text{HCO}_3) \\ = \text{H} + 0.1116 \text{ Al} + 0.0361 \text{ Fe} + 0.0828 \text{ Mg} - 0.0336 \text{ CO}_3 - 0.0165 \text{ HCO}_3$$

Stabler's final discussion and rules for interpretation are as follows:

229. "One of the first occurrences in a boiler is the precipitation of at least a part of the carbonate and bicarbonate radicles as calcium carbonate. Such precipitate can be acted upon, the calcium being returned to the chemical system to replace the hydrogen which forms water and carbon dioxide with the carbonate radicle. The extent of such action is not well defined. With a maximum precipitation of calcium carbonate and a minimum action upon the same, the effect of the carbonate and bicarbonate radicle in the above formula may be reduced by 1.008 $r\text{Ca}$ or .0503 Ca . The foregoing considerations afford an excellent basis for the classification of waters according to their corrosive tendencies. Three classes may be distinguished as follows:

- (1) Corrosive. If c be positive, the water will certainly corrode the boiler.
- (2) Non-corrosive. If $c + .0503 \text{ Ca}$ be negative, no corrosion will occur on account of the mineral constituents in the water.
- (3) Semi-corrosive. If c be negative, but $c + .0503 \text{ Ca}$ be positive, corrosion may or may not occur, the probability of corrosive action varying directly with the value of the expression $c + .0503 \text{ Ca}$."

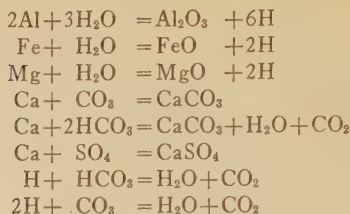
Notes

230. The equations aim to give the parts per million of hydrogen ions and therefore the factors are such as do this.

231. It will be observed that this "coefficient of corrosion" takes no account of dissolved oxygen which for practical purposes is the only cause of water corrosion (317). However, this does not altogether invalidate the equation. Unless specifically removed, oxygen is always present in a water and therefore in most cases the interpretation of Stabler will hold as well as any. (In this connection paragraph 353 should be read.) It must be remembered though that the concentration of oxygen is sometimes reduced without having the operation so labeled, as when the water goes through an open heater. Such facts, therefore, must always be known.

Scale Formation

232. The equations giving the measure of scale formation are based on the following reactions which, as Stabler says, are not intended to show the changes that take place in the boiler but to show the result of such changes.



233. The last two equations are put in merely to show that the CO_3 and HCO_3 ions may pair with H as well as with Ca and thus introduce an uncertainty into the distribution of Ca between CO_3 and SO_4 . This necessitates the use of an averaging factor for calcium which will be explained below.

234. The equations give the pounds of scale formed by 1,000 gallons of water. See Note 1 for meaning of Sm and Cm.

$$(10) \text{ Scale (Sc)} = .0083 \text{ Sm} + .0083 \text{ Cm} + .0.3 \text{ rFe} + .0.142 \text{ rAl} + .0.168 \text{ rMg} + .0.492 \text{ rCa} = .0083 \text{ Sm} + .0083 \text{ Cm} + .0.0107 \text{ Fe} + .0.0157 \text{ Al} + .0.0138 \text{ Mg} + .0.0246 \text{ Ca}$$

"In this formula the value of rCa used should not be in excess of $\text{rCO}_3 + \text{rHCO}_3 + \text{rSO}_4$. (Ca should not exceed $0.668 \text{ CO}_3 + 0.328 \text{ HCO}_3 + 0.417 \text{ SO}_4$)"

Stabler's interpretation of these equations is quoted from his paper:

235. "Formula (10) shows the amount of scale and sludge likely to be deposited in a boiler operated under the usual conditions of modern practice and its value will never differ widely from the "total incrusting matter" frequently reported from an estimation of hypothetical combinations of radicles. It is of equal importance to know whether the matter deposited will form a hard scale. The following formula shows in pounds per 1,000 gallons the probable amount of hard-scale-forming material in the scale:

$$(11) \text{ Hard scale (Hs)} = .00833 \text{ SiO}_2 + .168 \text{ rMg} + .567 (\text{rCl} + \text{rSO}_4 - \text{rNa} - \text{rK}) = .00833 \text{ SiO}_2 + .0138 \text{ Mg} + (.016 \text{ Cl} + .0118 \text{ SO}_4 - .0246 \text{ Na} - .0145 \text{ K})$$

The value used for the parenthesis of this formula must not exceed rSO_4 or rCa (.0118 SO_4 or .0283 Ca in the second form) nor should it be less than zero.

236. "Dividing the value of formula (11) by the value of formula (10), a factor will be obtained which may be called the coefficient of scale hardness. This factor shows the proportion of the total scale that is likely to form a cement-like substance upon the boiler tubes and is therefore an index to the probable hardness of the scale that will be deposited. Thus:

$$(12) \text{ Coefficient of scale hardness, } h = \frac{\text{Hs}}{\text{Sc}}$$

From formulas 10, 11, and 12, waters may be classed as follows:

- (1) Soft scale: h not more than .25.
- (2) Medium scale: h more than .25 but not more than .5.
- (3) Hard scale: h more than .5.

In addition, the following classification may be used as a prefix to the preceding:

- (1) Very little: Sc not more than 1.
- (2) Little: Sc more than 1, but not more than 2.
- (3) Much: Sc more than 2, but not more than 4.
- (4) Very much: Sc more than 4."

Notes

237. The symbol Sm means suspended matter and Cm means colloidal matter. The factor 0.0083 transposes parts per million into pounds per 1,000 gallons. An inspection of specimen analyses and their interpretation as given in Stabler's article leads one to think that if colloidal matter, which consists of $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$, is included, the iron and aluminium are not included in the equation.

238. The factors in the scale equations have the usual significance. On the basis of the reactions above they are the chemical factors for transposing parts per million or reacting values into pounds per 1,000 gallons. The ones for calcium, however, require special mention. As noted above, there is uncertainty regarding the distribution of calcium between carbonate and sulfate. One part of calcium would produce 2.5 parts of scale in the form of calcium carbonate or 3.4 parts in the form of calcium sulfate. Stabler avoided this dilemma by using the mean of these two factors or 2.95. In the second equation under (10) the scale factor for calcium is therefore $2.95 \times 0.0083 = 0.0246$, which means that the parts per million of calcium in the water multiplied by this factor gives the pounds per 1,000 gallons of mixed carbonate and sulfate of lime deposited in the boiler.

239. Calcium should not be in excess of that which can react with the CO_2 , HCO_3 , and SO_4 in the water because it is with these ions only that calcium forms scale.

240. Equation (11) is based on the assumption that all of the SiO_2 and Mg and part of the SO_4 go to the formation of hard scale, which may be considered a mixture of silica, magnesia, and calcium sulfate. The portion of the equation in the parenthesis determines what part of the SO_4 shall be counted. The assumption is made that it will all be counted except what is combined with or balanced by the sodium and potassium. This is a fair assumption because none of it will be with the magnesium since magnesium sulfate is supposed to hydrolyze in the boiler and give magnesium oxide. The only other positive ions are those of calcium, sodium, and potassium. The only portion of the sodium and potassium that can combine with the SO_4 is the part, if any, which is not combined with Cl, consequently the term $(r\text{Cl} + r\text{SO}_4 - r\text{Na} - r\text{K})$ is a measure of the SO_4 in excess of that combined with sodium and potassium. The factor 0.567 gives the calcium sulfate equivalent in pounds per 1,000 gallons.

241. Certain limitations, however, must be set to the possible values of the term in the parenthesis. These are pointed out by Stabler. For example, it is obvious that calcium sulfate can not form in excess either of the SO_4 or of the Ca, and therefore the value of the parenthetical term must not exceed $r\text{SO}_4$ or $r\text{Ca}$. If $r\text{Na} + r\text{K}$ is greater than $r\text{Cl} + r\text{SO}_4$, the value is negative or less than zero. This means that all of the SO_4 is combined with the sodium and potassium and consequently there can be no calcium sulfate.

242. In addition to the interpretative equations given above, Stabler has two which are pure calculations, one gives the soap-consuming power of a water and the other the lime and soda ash required for softening a water. These are given in this place in order to have all of the Stabler methods²⁹ together.

²⁹In Stabler's papers there are also equations for irrigation water, but since these have no application in Ohio they are not given.

Soap-Consuming Power

243. The equations are based on Whipple's data which are discussed in 269. They give the cost, in cents, of soap, at 5 cents a pound, that will be consumed by 1,000 gallons of water.

$$(4) \text{ Soap cost} = 11 + 50.05 (r\text{Fe} + r\text{Al} + r\text{Ca} + r\text{Mg} + r\text{H}) = 11 + 1.79 \text{ Fe} + 5.54 \text{ Al} + 2.5 \text{ Ca} + 4.11 \text{ Mg} + 49.6 \text{ H}$$

Notes

244. All of the substances that react with soap are included in the equation. For practical purposes calcium and magnesium only need be included. The equation then becomes, soap cost = $11 + 50.05 (r\text{Ca} + r\text{Mg})$. The equation in 269 is simpler to use with the analyses as given in this Bulletin.

245. The significance of the 11 in both equations is the same as that of the 2 in the equation given in 269. With soap at 5 cents a pound (Whipple's value) this equation becomes $10 + \text{H}$.³⁰

246. In both equations the part following the constant 11 is merely an expression for the total hardness. In the second equation of the pair the numbers preceding the symbols are the chemical factors for calculating the ions into the corresponding amounts of hardness, that is, into the equivalent of calcium carbonate. The constant 50.05 in the first equation is the factor for multiplying reacting values to obtain the equivalent amount of hardness or calcium carbonate. It is a combination factor as described in 87.

247. Whipple's data were compiled in 1907 in which year 5 cents a pound for average soap was justified. To bring the equation to any particular price of soap (1) multiply the price by 2 and substitute the value obtained for the 11; (2) multiply the price by 0.2 and use the result as a constant multiplier for all the numerical factors. For example, if the price of soap is 9 cents the equations become,

$$\begin{aligned} \text{Soap} &= 18 + (1.8 \times 50.05) (r\text{Fe} + r\text{Al} + r\text{Ca} + r\text{Mg} + r\text{H}) \\ \text{Soap} &= 18 + 1.8 (1.79 \text{ Fe} + 5.54 \text{ Al} + 2.5 \text{ Ca} + 4.11 \text{ Mg} + 49.6 \text{ H}) \end{aligned}$$

Water Softening Calculations

248. The equations give the pounds of 90 per cent lime and 95 per cent soda ash required to soften 1,000 gallons of water.

$$(5) \text{ Lime required} = 0.26 (r\text{Fe} + r\text{Al} + r\text{Mg} + r\text{H} + r\text{HCO}_3 + 0.0454\text{CO}_2) = 0.00931 \text{ Fe} + 0.0288 \text{ Al} + 0.0214 \text{ Mg} + 0.258 \text{ H} + 0.00426 \text{ HCO}_3 + 0.0118 \text{ CO}_2$$

$$(6) \text{ Soda ash required} = 0.465 (r\text{Fe} + r\text{Al} + r\text{Ca} + r\text{Mg} + r\text{H} - r\text{CO}_3 - r\text{HCO}_3) = 0.0167 \text{ Fe} + 0.0515 \text{ Al} + 0.0232 \text{ Ca} + 0.0382 \text{ Mg} + 0.462 \text{ H} - 0.0155 \text{ CO}_3 - 0.00763 \text{ HCO}_3$$

249. The coefficients used in these equations are, with the exceptions noted below, merely factors for multiplying the reacting values or the parts per million, as in the last parts of the equations, for obtain-

³⁰The author is unable to get the value 11 from Whipple's data. Perhaps he too does not understand the Stabler equation.

ing the required number of pounds of lime per 1,000 gallons of water. The number 0.0454 before the CO_2 in the lime equation is the reaction coefficient of carbon dioxide. It is not in Stabler's table and therefore had to be inserted.

250. The derivation of the factor 0.26 is as follows: Since lime (CaO) is to react with all of the substances in the parenthesis, it is evident chemically that the reacting value of the required lime will be equal to the sum of the reacting values of those substances. The problem then is to find a factor for converting this reacting value into pounds per 1,000 gallons. Dividing $r\text{CaO}$ by the reacting coefficient of CaO , 0.0357, gives the corresponding parts per million. Multiplying the p. p. m. by 0.0083 gives pounds per 1,000 gallons. This in turn must be divided by 0.90 to get the equivalent of 90 per cent lime.

$$\frac{r\text{CaO} \times 0.0083}{0.0357 \times 0.90} = 0.26$$

The factor 0.465 in the first equation of (6) is derived in the same general way.

251. The subtraction of the CO_3 and HCO_3 terms in (6) seems puzzling because at first glance it would appear that the soda ash precipitates nearly all the substances that are also precipitated by the lime. To understand this situation one must recall that if a positive ion is precipitated or neutralized with lime, a chemically equivalent amount of calcium remains in solution and must subsequently be precipitated with soda ash, unless the positive ion had been combined with CO_3 or HCO_3 . In these cases the added calcium is also precipitated. (See 406.) It is obvious then that though the lime will precipitate all of the iron, aluminium, and magnesium and neutralize all of the hydrogen ions, an exact equivalent of calcium will remain and will require its quota of soda ash, excepting in those cases in which the positive ion acted upon by the lime was combined with CO_3 or HCO_3 . Consequently the equivalent of these ions is subtracted.

252. It also follows, as Stabler points out, that if the values for CO_3 and HCO_3 exceed the sum of the others, in other words if a negative result is obtained in (6), no soda ash will be required.

253. Stabler also calls attention to the fact that since iron, aluminium, and hydrogen ions are rarely present in significant amounts they may be omitted from the formula for practical use. Bartow and Jacobson³¹ suggest the following simplification of the equations:

Lime = $0.0052 (4.16 \text{ Mg} + \text{Alk} + 2.27\text{CO}_2)$ lbs. per 1,000 gallons, 90% CaO .
Soda ash = $0.0093 (4.16 \text{ Mg} + 2.5 \text{ Ca} - \text{Alk})$ lbs. per 1,000 gallons of 95% Na_2CO_3 .

³¹Illinois Water Survey Bulletin 8, 88 (1911).

"Alk" in these equations is the same as the carbonate hardness as used in this Bulletin.

254. A footnote on page 170 of the article in Water Supply Paper 274 calls attention to the use of barium carbonate in place of some or all of the soda ash if much sulfate is present in the water (430), and gives the following formula for determining the minimum amount of soda ash that may be employed under such conditions:

$$\text{Soda ash (Na}_2\text{CO}_3) = 0.0131\text{Cl} + 0.0075\text{NO}_3 - 0.0202\text{Na} - 0.0119\text{K}.$$

In this equation the chemical symbols stand for parts per million and the factors are those which give the chemically equivalent number of pounds of 95 per cent soda ash per 1,000 gallons of water. It gives the soda ash requirement of the total nitrates and chlorides in the water less the nitrate and chloride combined with sodium and potassium, in other words, it gives the soda ash required by the nitrates and chlorides of calcium and magnesium. If the equation gives a negative value it means that all of the hardness constituents are present as sulfates and therefore no soda ash should be used. If the result is positive it should be subtracted from the soda ash value obtained in equation (6) to get that portion of the soda ash requirement for which barium should be substituted. The ratio is 1.77 lb. barium carbonate = 1 lb. soda ash.

CHAPTER VII

HARDNESS AND WATER IN THE HOUSEHOLD

The Behavior of Water in Use

255. The particular behavior of a water in use is of course determined largely by the particular use to which it is put, but, in general, it can be stated that as soon as one begins to handle the average water, for example, pump it, pour it, or convey it in pipes, that soon will the water begin to change and exhibit some form of behavior, usually bad. Dissolved gases such as carbon dioxide and hydrogen sulfide escape and air (oxygen and nitrogen) dissolve in the water. This escape of some gases and the taking up of others produces striking effects in many waters.

Hardness

256. The hardness or soap-destroying property of water is due to certain basic ions and is independent of the accompanying acid ions. The basic ions which cause hardness are those of the alkaline earths, barium, strontium, calcium, and magnesium, and of the iron group. Of these latter iron and aluminium are the only ones usually present in a water. Sodium and potassium though present in small amounts do not cause hardness. Of the list given above, calcium and magnesium are the only ones likely to be in a water to a sufficient extent to affect the hardness, and therefore the others need not be considered.

257. Though the soap-destroying action of hardness is due only to the basic ions, the behavior of the water in depositing scale and sludge and the nature of such deposits are determined largely by the acid ions in solution. Under the old nomenclature this fact is stated by saying that the form of combination of the calcium and magnesium determines the nature of the scale and sludge. For example, the incrustations depositing from water in the cold and the loose sludge that forms when hard water is boiled are due to the bicarbonates of calcium and magnesium, $\text{Ca}(\text{HCO}_3)_2$ and $\text{Mg}(\text{HCO}_3)_2$. These compounds decompose easily and form insoluble carbonates. (See 496 and 497 for the chemical discussion.) The hardness removed in this way is called temporary hardness.

258. The hardness caused by the salts of calcium and magnesium other than the carbonates and bicarbonates is called permanent because it is not affected by heating the water. The sulfates, chlorides, and nitrates of calcium and magnesium make up the bulk of the permanent

hardness. Calcium sulfate is fairly insoluble and will therefore precipitate if the water is evaporated.

259. Various other terms in addition to "temporary" and "permanent" have been employed to designate the two types of hardness. For example, "alkalinity" was used some years ago in place of temporary hardness because the bicarbonates of calcium and magnesium are alkaline and the method of determining them consists in titrating the water with acid. At the same time "incrustants" took the place of "permanent hardness" on the theory that that word expressed the peculiar characteristic of that form of hardness. These terms "alkalinity" and "incrustants" are now but little used and the Committee on Standard Methods of Water Analysis recommends the discontinuance of the expressions "temporary" and "permanent" as descriptive of hardness, and the use of the words "carbonate" and "non-carbonate" because, with proper definitions, these more nearly express the true state of the water. In effect, carbonate hardness means that part of the hardness which is due to the bicarbonates of calcium and magnesium, and non-carbonate hardness is the rest of the hardness or the total hardness less the carbonate hardness. A critical chemist, however, having in mind the methods by which the two kinds of hardness are determined must use the definition given in Standard Methods (page 27, 1923 ed.), namely, "When the total hardness is greater than the carbonate and bicarbonate alkalinity, the amount of hardness equivalent to the alkalinity is called carbonate hardness and the amount of hardness in excess of this is called non-carbonate hardness." As a definition this is intended to be water-tight. In all strictness, temporary hardness is that part of the total hardness which is removed by boiling. It does not exactly correspond to the calcium and magnesium bicarbonates in the water.

Water in the Household

Miscellaneous Effects

260. The incrustations seen in vessels in which hard water has stood consist of calcium carbonate which precipitated because carbon dioxide escaped from the water to such an extent that the carbonate could no longer be held in solution. The brown color frequently observed is due to iron.

261. Some waters though clear when first pumped become cloudy on standing and eventually deposit a gray or brown precipitate. This behavior is caused by iron or hydrogen sulfide or both. Iron in most ground waters is in the form of ferrous bicarbonate which, like calcium bicarbonate, decomposes when carbon dioxide escapes from the water. The white solid which first separates is probably ferrous carbonate. Through the action of the oxygen taken up from the air this ferrous

compound is slowly transformed into a basic ferric salt which changes in color as the transformation proceeds. The fine particles which had formed at first also collect together till eventually the precipitate settles to the bottom as a brownish deposit. This renders the water unsightly but does not indicate unwholesomeness for drinking. If such a water is used in the laundry the iron will deposit in the fabrics and produce "rusty" spots. Iron in the water is also the cause of brown spots on plumbing fixtures. The same effects will also be produced by a few tenths of a part per million of manganese in a water.

262. If a water contains hydrogen sulfide, easily recognized by its odor which is that of rotten eggs, there is also a change in appearance on exposure to the air. The oxygen of the air decomposes the hydrogen sulfide in such a way that the sulfur separates in the free state and makes the water turbid or milky. This turbidity is white because very finely divided sulfur has that appearance. In time the fine particles clump together and settle to the bottom. Sometimes a clear water on exposure to the air turns black. This is caused by the combined action of iron and hydrogen sulfide in the water and oxygen from the air, which forms sulfide of iron, a black substance. Sulfur waters are suitable for drinking if a taste for them can be acquired.

263. Iron in a water is the cause of "inky" cold tea sometimes observed by housewives. The iron reacts with tannin in the tea and produces ink. If such water must be used for tea it should first be aerated by pouring from one vessel to another and allowed to stand till the iron has precipitated and settled out.

264. The red color that appears sometimes in water, particularly from the hot faucet, is due to finely divided basic iron oxide. It does not indicate poison.

265. Municipal water supplies occasionally acquire peculiar odors and tastes. These may be due to growths of algae in the reservoir or they may come from an incidental action of chlorine used in purifying the water. Some waters contain minute amounts of substances capable of uniting chemically with chlorine to produce new substances many times as odoriferous as the original constituents. Such matter may at times come from the decomposition of the traces of organic material universally present in water but it is more likely to be due to coal-tar products that have entered the water through industrial wastes. When such odors occur the consumer should remember that the superintendent of the water purification plant is more anxious than any one else to get rid of them.

266. Surface waters are sometimes highly colored by vegetable matter dissolved from swamps. In Ohio there are no examples of such colored waters so far as the author knows, but many of them are found in New England.

267. The corrosion or pitting of steam and water pipes with con-

sequent formation of leaks is in most cases due to the water rather than to the metal. Soft waters are more likely to cause leaks than hard waters. For further particulars the reader must be referred to the more technical matter in the chapter on corrosion.

Waste of Soap Due to Hard Water

268. The action of hard water on soap is due to salts of calcium and magnesium. These salts react with the soap to form slimy, insoluble compounds which are easily seen in the water before a lather begins to form. The formation of these slimy compounds uses up soap and therefore the harder the water the more soap is consumed before lather is formed, and since the soap exerts no cleansing action till it lathers, it is clear that hard waters require more soap than soft waters.

269. Whipple³² studied the effect of hardness on soap and found that below 20 parts per million of hardness relatively more soap is consumed than in the case of higher hardness. For example, 6 lbs. (in round numbers) of average soap is required to soften 1,000 gals. of water of 20 parts hardness and 22.2 lbs. if the hardness is 100.

270.³³ An inspection of Whipple's tables shows that the first 20 parts per million of hardness consumes soap at the rate of 0.3 lb. per 1,000 gals. per part of hardness but that after that point is passed the rate is uniformly 0.2 lb. till 200 parts is reached.³⁴ If the rate of 0.2 lb. is taken as that of the whole range from one part up, the excess of 0.1 lb. over the first 20 parts of hardness can be put into the formula as the constant $0.1 \times 20 = 2$. The following simple equation is then obtained in which H equals the total hardness:

$$\text{Pounds soap consumed per 1,000 gallons} = 2 + 0.2 H$$

271. The wastage of soap in the household requires an estimate of the amount of water used with soap. It is a difficult estimate to make but the author has attempted it on the basis of measurements made in his own home. Two cases must be considered. First, in washing dishes and in the laundry, soap is added to water till a permanent lather forms. In other words, all of the water is softened before any soap becomes available for cleaning. The measurements showed that about 500 gallons of water a year are used in washing clothes and 1,000 gallons in washing dishes. These figures seem small but it must be remembered that they refer only to the water completely softened by soap. In laundry work, for example, the rinse water is not included.

³²The Value of Pure Water, John Wiley & Sons, p. 27.

³³The matter in paragraphs 266 to 276 inclusive is taken from a paper by the author, The Value of Softened Water, News Edition, Ind. and Eng. Chem., Aug. 20, 1924.

³⁴The table shows a distinct falling off in the soap consumption from 175 to 200 parts of hardness. Since many Ohio waters run much higher than 200 in hardness this point should perhaps be investigated.

It must also be remembered that dishwashing comes two or three times a day while laundry work is a weekly event. The second case involves the use of soap in the toilet. Very little of the water in the bowl or tub is completely softened by the soap, particularly if the water is very hard. Indeed only the small amount actually rubbed on the skin is so softened. It is hard to estimate this, but to be conservative it is put at 20 gallons a year for each person. For a family of five then the total amount of water annually completely softened with soap is 1,600 gallons.

272. Since some Ohio cities are now softening their water and others are considering doing it, it is worth while to give some figures to show what such softening of the water means to the average household.

273. Columbus has had municipal softening now for fourteen years, and it is interesting to calculate the saving in soap. In 1922, which was typical, the raw Scioto River water averaged 288 parts per million in hardness, and the softened water, as delivered to the consumer, averaged 101 parts. The hardness removed was therefore 187 parts, and on applying the equation above it is seen that on the basis of 1,600 gallons of water completely softened each year with soap, 63 pounds of soap are saved. At 10 cents a pound for household soap this makes \$6.30.

274. This loss of soap is, however, not the only item of household expense due to hard water. The slimy precipitate formed by the action of the calcium and magnesium salts settles in the clothes during washing and gives them a grayish, dirty look. Indeed its presence interferes with cleansing in whatever way a hard water is used with soap. In addition the salts which cause hardness also cause the scale which deposits in tea kettles and in the water pipes generally in a house.

Extra Cost of Soft Water Equipment

275. There are, however, other items in favor of the household use of soft water. Those who live in hard water towns know that the average house is supplied with a cistern and a pump for lifting the soft water. In the better houses this pump is either electrically driven, or, as used to be the case, is operated by the water pressure in the city mains. The less expensive houses are equipped with hand pumps. The author has recently obtained from a plumbing concern in one of Ohio's hard water cities the following itemized statement showing the additional cost of plumbing an ordinary six or seven room house with this double system as compared with the plumbing of the same house in Columbus or other soft water city. The hard water extras are as follows:

100 barrel cistern.....	\$100.00
Electric pump.....	132.00
Installing pump.....	15.00
Extra plumbing for cistern water.....	45.00
<hr/>	
Total.....	\$292.00

276. With interest at 6 per cent and depreciation and repairs at 3 per cent, this extra soft water equipment entails an annual cost of \$26.28. The low estimate for repairs and depreciation is justified by the fact that the moving parts are in operation for only a few hours each week.

Savings Due to Soft Water

277. As a problem in accounting now, how much does the Columbus householder save as a result of his municipal softening plant? That will depend on his previous practice. If he formerly used the hard water he saves the annual wastage of \$6.30 worth of soap. If he formerly had a double system of plumbing he saves \$26.28 a year in interest, etc., but not the \$6.30 for soap because he formerly had soft water from his cistern. If the cistern water had been rain water of zero hardness there would have been a greater saving of soap under the old scheme than under the present one but since these old cisterns were nearly all built of concrete it is doubtful whether they furnished on an average a softer water than that supplied at present. One very interesting conclusion can, however, be drawn from the Columbus situation. All but the poorer houses had the double plumbing and since the average householder knew little or nothing of the wastage of soap by the hard water but considered only the annoyance and trouble incident to its use, it is reasonable to conclude that he paid for his extra plumbing not to save money on soap but to be spared the annoyance of using hard water. In other words, he was willing to expend \$200.00 (a fair figure for twenty years ago) on extra plumbing merely to add to the comfort of his family.

The net saving then to the Columbus householder is the annual expense of the extra soft water equipment, \$26.28, less the extra cost of water due to softening. This amount is certainly not more than \$3.28 so that the net saving in money may conservatively be put at \$23.00 a year, and in addition the annoyance and discomfort of hard water are removed.

278. The question now should be raised and answered, what does this softening cost the Columbus householder? That cannot be answered accurately because the purification plant also filters and sterilizes the water so that it is of high sanitary quality. The household rate for this highly purified water is 16 cents per 1,000 gallons. Mr. Hoover, the superintendent of the plant, has called attention to how inexpensive this good water seems if its price is calculated on another basis. It amounts

to 3 cents a ton. Where could anything else so valuable be purchased at that price, delivered?

Limit of Municipal Softening

279. One may also very properly raise the question of pushing the softening further than 100 parts per million, which is, after all, a hard water. The answer lies both in economics and psychology. When 100 parts has been reached in softening a very hard water the further removal of hardness is relatively more costly, by the lime and soda ash method. At best the softening could not profitably be pushed much below 80 parts per million. The psychology of the situation lies in the fact that 100 parts marks the dead line of hardness above which it is not safe to leave the water or the superintendent of the plant will be showered with complaints. In other words, the people stand for 100 parts of hardness but not for more. It is worth noting in passing that first-class laundry work can be done at home with this amount of hardness in the water.

Palatability of Softened Water

280. Finally, consumers are often doubtful of the palatability of softened water. The author, for example, has frequently been told that "while it is very nice to have our clear soft water, yet it doesn't taste quite right." His invariable reply was, "It is doubtful if you can tell the difference." This, however, was always scouted. Now it is possible to refer to a direct experimental test of this question. Lansing, Michigan, has a very fine-tasting water but unfortunately a very hard one, 360 parts per million. The question of softening was affected by the fear that the "chemical treatment" would lower the palatability. Indeed this was such a large issue that at the demonstration softening plant that was installed, a large scale experiment was made as follows: Two drinking fountains were erected and provision made for supplying untreated water to one and softened water to the other. Both waters were kept at the same temperature. According to the report made last summer at the Detroit Meeting of the American Water Works Association, about 3,000 persons visited this demonstration plant and a careful record was kept of the opinions of 350 people who tried both waters. One hundred said that they could not tell the difference and did not try to guess. Two hundred and fifty guessed and of these fifty were wrong. Of the 200 who were correct, all said that the softened water was palatable, they merely could tell the difference. This large-scale experiment would seem to dispose of the bugaboo of unpalatability of softened water.

Soft Water for the Isolated House

281. Since a supply of clear soft water free from iron is of such great value in the household, the question of how to obtain it for an isolated house naturally arises. Hard waters can be softened, but with the exception of a zeolite system as described in Chapter XI the author knows of no general procedure for doing it. If a given hard water is of fairly constant composition, as would be the case with well waters, a competent chemist could easily devise a mixture for softening it, but this mixture would apply only to that particular water.

282. The most feasible plan for obtaining an isolated household supply of soft water in Ohio is to collect rain water. The rainfall in Ohio is such that the roof area of the average homestead is ample for the gathering of all the water that a household needs. The point at which this plan usually fails is in not having a sufficiently large cistern. This must be large enough to tide over the longest dry spell. The average cistern is only about half that size.

CHAPTER VIII

SCALE, BOILER COMPOUNDS, AND INTERNAL TREATMENT

*Scale*³⁵

283. When a water containing dissolved mineral matter is used for making steam some of the mineral matter will separate in the solid form, and in boiler practice these separated solids are classified according to their property of adhering to the walls of the tubes or shell of the boiler. The part that attaches itself firmly to the interior of the boiler is called scale and the portion that does not so adhere, but remains as a loose mud, is called sludge or sediment.

Factors Determining the Adherence of Scale

284. The tenacity with which scales adhere to the metal of the boiler varies greatly. The removal of some requires a hammer and cold chisel while others can be washed off with a stream of water. This property of adhering is determined by the chemical nature of the deposit and that of the material upon which deposition takes place. It is likely also that the rate of deposition of the scale plays a role. Since boilers are almost universally constructed of steel, the factors involved in the material upon which deposition takes place are constant,³⁶ and therefore the tenacity with which the scale adheres to the metal is conditioned almost entirely by the nature of the deposit and the rate of deposition. Of these, the former is more important. In so far as the latter comes into play it is probably in the sense that the deposit will be harder and adhere more closely the slower it forms.

285. Hall, Fischer, and Smith³⁷ have recently advanced the theory that in a steam boiler those substances whose solubility decreases with increase of temperature form adherent scale, and those substances whose solubility increases with increase of temperature form the loose sludges. This theory is based on the results of a number of laboratory experiments made in a glass apparatus containing a heating element

³⁵The matter on boiler scale as presented here includes certain general points only. In the author's opinion an extensive discussion of scale would be unprofitable because the strategic point of attack on this problem lies in getting rid of the scale-forming constituents in the water rather than in studying the scale itself.

³⁶There are few if any methods of applying to iron a coating which will withstand the conditions in the interior of a high pressure steam boiler, otherwise attempts to modify the surface of a boiler might be a profitable field of research. It is worth a passing note, however, to record that there is a type of boiler compound that, its manufacturers claim, does this very thing. It is added to the feed water at wide intervals of time and a large dose used at each addition. The effect is supposed to be such a modification of the surface of the interior of the boiler that scale will not adhere.

³⁷Iron and Steel Engineer, June, 1924. The same matter is presented in a somewhat more chemical way in a paper by Hall, "A System of Boiler Water Treatment Based on Chemical Equilibrium." Ind. and Eng. Chem. 17, 283 (1925).

of nichrome ribbon, and also on results obtained with boilers of different designs. When a solution of calcium sulfate, hydroxide, or chromate was evaporated in the glass apparatus an adherent crust formed on the hot ribbon. These substances are all less soluble in hot than in cold water. Substances, on the other hand, that are more soluble in hot water than in cold (calcium iodate and potassium sulfate were used) formed loose non-adherent deposits that separated in the cooler parts of the apparatus. The most interesting experiment was made by evaporating a solution of calcium sulfate at reduced pressure, below 35° C., in which region the solubility increases with increasing temperature. Under these conditions precipitation did not occur on the hot nichrome heating element but on the cooler glass surfaces. Hall and his co-workers do not suggest a reason for this relation of adherence and localization of the area of least solubility, but so far as boiler scale behavior goes it is not necessary because they show not only with their experimental glass apparatus but also by actual runs made with steam boilers that there is that correlation of properties, at least in the case of those substances that cause deposits in the boiler.

Chemical Causes for the Deposition of Scale and Sludge

286. The chemical reasons for the deposition of scale and sludge from a boiler water fall under three headings:

- (1) Separation of solid matter because of concentration in the boiler. Even very soluble salts eventually begin to separate in the solid form if their solutions are boiled down.

- (2) Chemical decomposition of soluble substances by heat with the formation of insoluble compounds.

- (3) Separation of substances that become less soluble as the temperature rises.

287. Chemical decomposition by heat of constituents existing in the cold water with the resulting formation of insoluble substances is one of the most potent causes of scale and sludge. Calcium and magnesium bicarbonates decompose at high temperatures with the formation of the insoluble calcium carbonate, with occasionally some magnesium carbonate. At the high temperature of a boiler magnesium salts hydrolyze, that is, react with the water, and form insoluble magnesium hydroxide. Various solid compounds of iron, hydroxides and basic salts, are also formed by decomposition of bicarbonates and by hydrolysis. Calcium sulfate may result from the interaction of calcium carbonate with sodium or magnesium sulfate.

288. Reduction in solubility due to increase in temperature is the main reason for the separation of calcium sulfate. This substance is practically insoluble at the temperature of a high pressure boiler and consequently precipitates.

Composition and Character of Scale and Sludge

289. The main constituents of most boiler water deposits are carbonates of lime and magnesia, hydroxide of magnesia and sulfate, and silicate of lime. Substances present in smaller amounts are silica, organic matter, and salts of sodium, iron, and aluminium. Oil from the use of unpurified condensed steam is frequently present to the extent of several per cent, and in special cases the amount may reach 30 or 40 per cent. As a rule one of the main constituents as listed above greatly predominates, running from 60 to 90 per cent of the whole.

290. There are, for example, scales and sludges consisting chiefly of calcium carbonate and others in which the main constituent is calcium sulfate. These are perhaps the most common. Next in order are those in which magnesium hydroxide runs the highest, and occasionally one is found in which calcium silicate is the main constituent. There is no general rule as to which substance will be next in amount under the predominating one. This, as well as the whole composition, is determined of course by the composition of the water entering the boiler and by the conditions in the boiler. Scales deposited in different parts of the same boiler or in the same part at different times may differ greatly in composition though the water used may have been the same throughout. The composition of the feed water gives only the most general suggestions as to the nature of the boiler deposits from it.^{37a} The amount of sludge and scale is, however, roughly proportional to the total hardness of the water. Table XVII gives analyses of various types of scales.

TABLE XVII

Analyses and Classification of Boiler Scales (Per Cent)

(Compiled by R. E. Hall, Ind. and Eng. Chem. 17, 283 (1925).)

No.	Type of scale	SiO ₂	Al ₂ O ₃ + Fe ₂ O ₃	CaO	MgO	Na ₂ O	SO ₃	CO ₂	Loss at 105°	Net ignition loss
1	Sulphate.....	1.5	2.2	38.6	1.6	....	54.5	0.0	0.5	1.5
2	Sulphate.....	3.1	1.2	36.9	5.9	....	45.6	3.3	0.2	4.0
3	Sulphate.....	0.7	0.4	39.0	2.5	....	55.4	0.0	0.2	1.7
4	Sulphate-carbonate.....	4.2	1.2	37.5	11.2	....	24.1	15.7	0.4	5.5
5	Carbonate.....	0.7	1.2	51.1	3.7	....	0.4	42.1	0.1	1.0
6	Carbonate.....	1.5	1.0	52.9	1.8	....	0.8	40.1	0.1	2.0
7	Carbonate-silicate.....	17.1	1.8	26.1	22.8	....	0.9	20.2	1.6	9.4
8	Carbonate-silicate.....	9.7	1.7	29.1	24.2	....	0.8	22.7	1.5	10.1
9	Carbonate-silicate.....	10.4	1.2	22.1	35.0	....	0.2	17.1	0.5	13.9
10	Carbonate-silicate-sulphate..	12.0	1.4	34.1	14.1	....	10.4	22.2	0.5	9.8
11	Carbonate-silicate-sulphate..	6.9	0.6	45.7	5.8	....	4.5	31.6	0.4	5.6
12	Sulphate-silicate.....	6.4	0.4	34.3	8.0	....	44.0	1.7	....	4.3
13	Sulphate-silicate.....	6.0	4.2	31.8	9.2	....	43.4	0.2	....	6.6
14	Silicate.....	45.4	6.9	32.9	1.8	6.7	0.7	2.1	1.4	4.6
15	Silicate.....	48.3	2.5	29.9	3.2	5.7	2.8	2.2	1.6	5.2

^{37a}Bartow and Mohlman, University of Illinois Bulletin, Water Survey Series No. 11, p. 156, studied the relation of mineral content of boiler waters to the scale formed but could find no close correlation.

291. In addition to those substances depositing from the water there may also be solids suspended in the water when it enters the boiler. These would in part settle out and make up a certain quota of the sludge, or might be cemented together in the scale.

292. The important physical characteristics of boiler water deposits are the hardness and the adhesiveness to the interior of the boiler. In general parlance hardness is used as synonymous with adhesiveness, and consequently a "hard" scale means one that not only resists penetration but also adheres firmly to the walls of the boiler. In general the calcium carbonate deposits are soft and non-adherent. They constitute the sludges. Calcium sulfate scales are hard and adhere tenaciously to the iron, and are even harder if they contain much magnesium hydroxide. Calcium silicate scales are also very hard. Non-adherent sludges consisting of almost pure magnesium hydroxide have been reported. The substance was very light and powdery, and in one instance resembled aluminium powder. Since the hardness of a deposit is probably a function of its rate of deposit, and perhaps, too, of several other factors, as well as of its chemical composition, it is impossible in some cases to predict the physical character from the analysis.

293. A given scale is seldom a pure chemical compound, but consists of a mixture of substances deposited together sometimes in layers. Because of this it often happens that the conditions are right for the cementing together of relatively large amounts of soft material by some hard, strongly adhesive deposit.

294. Changes may and undoubtedly do take place after the deposition of a scale. Since it is rather a poor conductor of heat the portions next to the iron become very hot, so hot indeed as to cause partial decomposition the net effect of which is to harden the scale. It is, so to speak, baked on the walls of the boiler.

Deposits Other than in Steam Boilers

295. The formation of scale and sludge on heating a hard water is independent of the vessel in which the heating is carried out, therefore every such container from a tea kettle to a fuel economizer will suffer. The chemistry of any given situation can be inferred by a study of those sections that deal with chemical changes in open heaters (496 and 497) and in steam boilers. The fundamental difference is one of temperature. In closed vessels like steam boilers the temperature of the water may be many degrees above the boiling point, and it is this rather than the increased pressure which brings about chemical changes in addition to those that go on at or below the boiling point.

296. It must be noted also that scale and sludge may, and frequently do, deposit from cold water. Many cases are on record in

which the mains conveying a city supply have filled up with scale. Such deposits are usually calcium carbonate or ferrous hydroxide, or, in rare instances, of hydrated oxide of manganese. A thread-like organism known as crenothrix seems to have the power of decomposing iron and manganese compounds, with the result that hydroxides are deposited. These sometimes stop up water mains. Many instances of manganese incrustations are described by Bartow and Corson.³⁸ It might be worth noting in passing that all of these deposits, even when they consist of hard calcium carbonate scales, can be cleaned out mechanically more cheaply than they can be dissolved out with acids.

297. At least one case has been reported to the author in which the deposit exhibited a selective action with respect to the nature of the surface. The agent for a meter company related that a jelly-like substance precipitated in the meters of a certain town and that when these meters, the working parts of which were brass or bronze, were replaced with a cheaper design built of iron the trouble ceased.

Boiler Compounds, Internal Treatment

298. Boiler compounds are substances introduced directly into a boiler to correct or eliminate the evils of bad feed water. They are the patent medicines of boiler rooms, and like the patent medicines of the almanacs many are worthless,^{38a} some are harmful, and some are good. The worthless and harmful predominate so that of late years an effort is being made to escape the evil reputation of the past by introducing a new term, "internal treatment."

299. Many writers are prejudiced against internal treatment but this seems unwarranted and contrary to common sense. Boiler compounds can be applied at once without equipment of any sort, and are, therefore, the ideal remedy for emergencies or temporary situations. They are generally intended to correct the troubles of scaling but they are also made to remedy corrosion and foaming, and some are to be found that pretend to be panaceas for all three troubles.

300. An inspection of the analyses of a number of boiler compounds shows a seemingly unclassifiable list of constituents such as caustic soda, soda ash, lime, sodium bicarbonate, tannates, sugar, wood extracts, molasses, sawdust, sand, ground glass, bran, potatoes, talc, starch, petroleum, glycerine, alcohol, coloring matter, and perfumery.³⁹

³⁸Occurrence of manganese in the water supply and in an incrustation in the water mains at Mt. Vernon, Ill., University of Illinois Bulletin, Water Survey Series No. 10, p. 57.

^{38a}French, Ind. and Eng. Chem. 15, 1241, gives an account of fake boiler compounds, their composition, and the claims made for them in their advertising matter.

³⁹Andés reports a compound consisting of a 46% solution of sugar in water, colored and perfumed. Der Kesselstein. A. Hartleben's Verlag, Wien und Leipzig, page 200 (1910).

Possible Effects Obtainable with Boiler Compounds

301. Before undertaking to study such a miscellaneous collection of substances, the use of which has grown up in a purely empirical fashion, it will be well to set down in the light of modern chemistry the various effects that, on theoretical grounds, there is any hope of obtaining by the use of substances in the boiler. It must not be supposed that all of these effects are equally attainable. Some, like Nos. 7 and 8 below, are ideals of future research.

1. The hydrogen ion concentration of the water can be changed. Practically, it will be decreased by the introduction of alkaline substances to reduce or prevent corrosion.

2. Scale-forming constituents can be precipitated. This is the fundamental purpose of most compounds. Lime and soda ash are the least expensive reagents for such use, as they are for softening. However, caustic soda is frequently employed instead of lime in order to obtain a liquid mixture. The tannates also precipitate the scaling constituents to some extent.

3. The scale can be prevented from adhering to the inside of the boiler. This is accomplished by the use of protective colloids, organic substances that have the effect of keeping the particles of precipitated matter such as calcium carbonate and sulfate and magnesium hydroxide from agglomerating into large masses and cementing together. Certain forms of inert material such as talc, graphite, and clay are also supposed to have this effect.

4. The scale-forming substances can be kept in solution. Sugar and molasses have this effect to a small extent at least. The saccharates of calcium are soluble.

5. Old scale can be loosened. An excess of soda ash acts this way and apparently certain inert substances also have this effect. Claims are made, for example, that the use of graphite will clean out a badly scaled boiler.

6. The surface tension of the water can be changed and the stabilization of the foam can be prevented. These effects would reduce foaming.

7. The character of the surface of the boiler can be changed so that scale will not stick to it. Claims of this character are made for some compounds. It has also been claimed that the surface of the boiler can be made passive and immune to corrosion.

8. The dissolved oxygen in the water can be combined by the use of a reducing agent and in this way prevent corrosion. No claim of this kind has, so far as the author knows, yet been made for a compound. It is as yet an unexplored field into which the faker will probably make the first excursion.

302. From a practical standpoint, the chief effect of a good boiler compound is the reduction of scale trouble. It accomplishes this by preventing the scale from sticking to the boiler. The effect noted in No. 4 above is probably negligible. The calcium and magnesium salts are precipitated rapidly by the lime, or caustic soda, and soda ash of the compound. This very rapidity of precipitation in large measure prevents adherence to the boiler plates and tubes but in addition there is probably some protective colloid effect of the organic matter. The net result is a non-adhering sludge that can be blown or washed out. In no wise is the precipitation of the scaling substances inhibited. They are completely precipitated but they are prevented from sticking to the boiler.

303. With the above points in mind it is seen that no universally applicable compound can be made. The economical precipitation of the lime and magnesium salts requires that the precipitants in the compound be apportioned to the composition of the water. This can be done only from the analysis. Reputable compound manufacturers therefore always require an analysis of the water before prescribing a boiler mixture.

304. The outstanding question seems to be that of deciding between the use of boiler compounds, which may be called internal treatment, and softening, or external treatment. The opinion among writers is almost unanimous that with the relatively hard waters of Ohio an outside softening equipment is by far the better plan. For the emergency, the temporary situation, and the special case, however, internal treatment or the use of compound is the only economical scheme.

High Cost of Boiler Compounds

305. Complaint and criticism are often made of the high cost of compounds as compared with the inexpensive materials from which they are made. That such a disparity exists is true but it must be remembered that even the most honest compound manufacturer must do much more than purchase raw materials. He has all of the usual overhead, the largest item of which is perhaps the cost of advertising and selling. If the owner of the boiler does not want to pay a high price per pound for a strong solution of caustic soda, soda ash, and molasses, he can reflect that he is always at liberty to employ a chemist of his own to analyze the water and prescribe a mixture to be used in his boiler.

Illinois Water Survey Experiments with Boiler Compounds

306. Reference has already been made to the possibility of actual harm resulting from the use of a poor compound, or of one not adapted to the conditions. Such harm is likely to take the form of corrosion

or of foaming. Bartow and Marti⁴⁰ conducted a series of laboratory experiments with a number of compounds and different waters. Their conclusions given below are interesting and perhaps typical:

1. "The corrosion varies with the alkalinity, showing that an increase in alkalinity makes the water less corrosive, due probably to the formation of hydroxide.

2. "The waters treated with sumach (this was sumach extract, the active principle of which consists of tannates), are an exception. In such waters alkalinity, non-carbonate hardness, and total hardness are almost unchanged, but the amount of scale formed is lowered. The corrosion increases continually.

3. "The magnesium does not reach a minimum, which is as low as the solubility of the hydroxide.

4. "Wherever there is a decrease in the amount of scale formed, the corrosion increases. When sodium carbonate is used, the foaming becomes so prominent that it makes this method of treatment impractical.

5. "In none of the experiments are the results ideal, and further experiments should be carried on with waters of a different character."

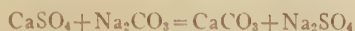
Hall's "Conditioning" of Boiler Water

307. Reference has already been made (285) to the work of Hall, Fischer, and Smith, and their theory that those substances in a boiler water which become less soluble as the temperature rises will necessarily precipitate in the film of liquid next to the hot metal and will in consequence adhere and form a hard scale, while those substances which are more soluble in hot than in cold water will necessarily precipitate in the cooler parts of the boiler and thus will form a loose sludge. According to this classification, the sulfate and hydroxide of calcium and the hydroxide of magnesium should form hard scale and the carbonate of calcium a soft non-adherent deposit. On these facts Hall reasoned that if the precipitation of the sulfate and the two hydroxides on the walls and tubes of the boiler could be prevented, hard scale would be eliminated. He solved this problem by adding an excess of soda ash to the feed water so that the mass action of the excess concentration of carbonate ions lowered the solubility of calcium carbonate below that of the sulfate at the temperature of the boiler. This would seem at first thought to be nothing more than precipitating out the calcium by means of the soda ash. The situation is, however, more complex than that as the following will show, though the reader should not lose sight of the main fact, namely, that the whole scheme consists in maintaining such a concentration of carbonate ions in the water that the solubility

⁴⁰Bartow and Marti, Treatment of water with boiler compounds, Illinois Water Survey 8, 59.

of calcium carbonate is less than that of the sulfate under all conditions.

308. When sodium carbonate (soda ash) is added to a boiler water it precipitates the calcium of the calcium sulfate present and there is formed a corresponding amount of sodium sulfate, according to the reaction,



The sodium sulfate increases the concentration of the sulfate ions and consequently the solubility of calcium sulfate in the water is diminished by the common ion effect just as that of calcium carbonate was reduced. Furthermore, this sodium sulfate continually concentrates in the boiler as water evaporates. This continually increases the concentration of the sulfate ions so that unless something is done to prevent it a point would presently be reached at which the sulfate would again become as insoluble as the carbonate and would precipitate. If the excess carbonate of sodium also concentrated in the same way as the sulfate, the situation would adjust itself but it does not do so, because, owing to the high temperature of the water the carbonate partially decomposes into sodium hydroxide and carbon dioxide. The latter escapes with the steam. There must therefore be some means of following the increase in concentration of sulfate and the decrease in concentration of the carbonate so that proper adjustments can be made from time to time. This is done by determining carbonate and sulfate in the water in the boiler. Fortunately these determinations can be made easily and rapidly by an intelligent engineer. The scheme of conditioning⁴¹ the water, as the author calls it, is then briefly as follows: By means of occasional determinations of sodium carbonate and sulfate in the water the rate of addition of sodium carbonate is so adjusted that the concentration of the carbonate is always maintained at such a point that the solubility of calcium carbonate is less than that of calcium sulfate in the resulting solution. A diagram is given in the original paper showing how the carbonate concentration is to be varied as the sulfate concentration increases.

309. The concentration of hydroxyl ions produced by the decomposition of the sodium carbonate almost completely precipitates the magnesium in the water as magnesium hydroxide, so that in spite of the fact that magnesium hydroxide precipitates on the hot surfaces there is practically no precipitate formed in that way because there is such a small amount of magnesium ions in solution.

310. There remains now an important special case to consider. If the pressure of the boiler is at or above 210 pounds the temperature of the water is so high that the sodium carbonate decomposes into hydroxide at such a rate that the proper concentration of carbonate ions can

⁴¹The methods and apparatus for this analytical work are described in the original paper, and also in a paper by Hall, Ind. and Eng. Chem. 17, 409 (1925).

not be maintained. Under these conditions Hall recommends the use of sodium phosphate instead of carbonate. It reacts with calcium to form the very insoluble calcium phosphate which in the presence of an excess of phosphate ions is more insoluble under the conditions of the boiler than the calcium sulfate. It therefore precipitates and the formation of hard sulfate scale is avoided. Sodium phosphate is more expensive than sodium carbonate and consequently it is not employed as long as the carbonate will serve.

311. Hall and his co-workers also point out that in a water containing a high concentration of caustic soda, whether resulting from the decomposition of sodium carbonate or from the direct addition of caustic to the water, the solubility of calcium hydroxide may be reduced to such a point that it will tend to precipitate on the hot metal surfaces and cause hard scale.

312. Finally it should be said that Hall, Fischer, and Smith made a number of actual runs with boilers using Monongahela River water. With this water much hard scale was formed, but when the same water was conditioned as described above only a thin, easily detachable film of scale was produced. The rest of the deposit was non-adherent sludge.

313. There are also many interesting mechanical features described in this paper, for example, one by which the sludge is kept down by a process of continual filtration and one by which the water is removed from the steam by centrifugal action, but since this is essentially a chemical bulletin these appliances will not be described.

This whole physico-chemical study of boiler water conditioning will undoubtedly be published eventually as a bulletin of the United States Bureau of Mines. In the meanwhile readers must content themselves by reference to the individual paper.

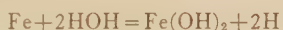
CHAPTER IX

CORROSION⁴²

314. What will be stated in this chapter concerning corrosion is intended to apply to sub-aqueous corrosion only, that is, to metal continuously in contact with water and not to situations in which the metal is alternately wet and dry as is the case on exposure to the weather. A large share of the conflicting statements in the literature of corrosion is due to a disregard of these conditions.

Electrolytic Theory of Corrosion

315. There are perhaps few practical problems, the solutions of which have been promoted to a greater degree by theoretical considerations than has this one of sub-aqueous corrosion, and therefore it is worth while to give the most commonly accepted theory, the so-called electrolytic one. This postulates that iron is slightly soluble in water according to the equation,



316. In pure water or in any ordinary, naturally occurring water this reaction is an exceedingly weak one; no more than the merest trace of iron dissolves. Indeed the reaction proceeds to such a small extent that if this were all there is to the matter there would be no problem of corrosion by water. Since, however, there is a problem of corrosion by water it is necessary to account for it by some factor in addition to the mere solubility of iron. This additional factor is the action of the oxygen in the water; not the oxygen of the water molecule itself, the O of H_2O , but the oxygen of air dissolved in the water. This may amount under favorable circumstances to as much as 10 parts per million by weight which is almost the same thing as 10 cc. of oxygen per liter.

Effect of Dissolved Oxygen

317. The effect of this oxygen is two-fold: (1) It oxidizes the ferrous hydroxide, $\text{Fe}(\text{OH})_2$, to ferric hydroxide, $\text{Fe}(\text{OH})_3$, and thus destroys the equilibrium expressed in the equation above, which in turn tends towards bringing more iron into solution. The effect though is small in comparison to that produced by the action of the oxygen on

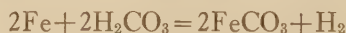
⁴²Some of the matter in this chapter is from a paper read by the author at the Ohio Conference on Water Purification, Columbus, Ohio, November, 1921. See also *Fire and Water Eng.* 76, 259 (1924).

the liberated hydrogen. This hydrogen is small in amount and therefore does not escape as a gas, H_2 , but remains on the surface of the iron as a film and prevents further action. It polarizes the iron. The dissolved oxygen oxidizes this film of hydrogen to water. This depolarizes the iron and permits further solution. It is seen from this that the oxygen removes both products of the reaction involved in the solution of iron in water and thus of course greatly promotes that reaction, for if the dissolved matter is transformed or removed from a solution the effect is the same as putting on fresh solvent and consequently more solid will dissolve. This removal or transformation of ferrous hydroxide and hydrogen continues as long as there is any oxygen and therefore solution of the iron continues as long as oxygen is left. In other words, corrosion is proportional to the concentration of dissolved oxygen in the water. This has been proved experimentally for the condition of natural water acting on iron or steel. It can thus be said that corrosion, though primarily due to the solubility of iron in water, is in a practical sense, due to the dissolved oxygen in the water.

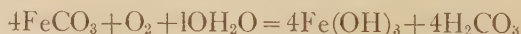
Other Theories of Corrosion

(1) The hydrogen peroxide theory. This assumes that oxygen takes part in the initial reaction and that hydrogen peroxide is one of the products. Some of this hydrogen peroxide then oxidizes the ferrous ions to ferric and another portion reacts with more iron to form more ferrous ions and water. This theory has been superseded by others and therefore further details will be omitted.

(2) The carbonic acid theory. According to this the initial reaction is between carbonic acid and iron according to the reaction,



The next step is the action of oxygen and water on the ferrous carbonate as follows,



This reaction, it is seen, sets free carbonic acid which then reacts with more iron. Since oxygen is the only substance present in limited amount solution of the iron will continue till the oxygen is exhausted. There are many points of similarity between this theory and the electrolytic one. For example, the first reaction is the solution of iron accompanied by the setting free of hydrogen. The next step depends upon the presence of dissolved oxygen. If oxygen were absent, corrosion would be incipient only.

This theory has lost standing from the fact that careful experiments show that water containing dissolved oxygen but *no carbonic acid*

brings about the rapid rusting of iron. (See Whitney, J. Am. Chem. Soc. 25, 394.)

(3) The colloidal theory. This was advanced by Friend (Proceedings Chem. Soc. 119, 932 (1921), and apparently was suggested by the fact that iron in water which is moving above a certain minimum rate does not rust as fast as in still or slowly moving water, and if the movement of the water over the iron is faster than about six miles an hour no corrosion takes place. The electrolytic theory does not account for this phenomenon. (Wilson, Ind. and Eng. Chem. 15, 129 (1923), disputes these statements about the relation of moving water to corrosion.)

The essential points of Friend's colloidal theory can best be given by the following quotation from his article cited above:

"Since the rapidly moving water inhibits corrosion, it would appear that it sweeps away from the surface of the metal some catalyst which assists the metal to corrode, and in the absence of which the metal simply dissolves in the liquid ionically with such small velocity that it is almost 'passive.' This catalyst must be derived from the iron, and the author believes it to be the hydrosol of iron hydroxide.

"It is therefore suggested that:

"1. Iron is 'noble' or passive towards distilled water in the absence of a catalyst and passes into solution, but only with extreme slowness, owing to the traces of electrolytes that are present.

"2. The dissolved iron is probably at first present in a more or less completely ionized ferrous condition, but is rapidly converted into the sol of ferrous hydroxide.

"3. This sol then undergoes oxidation by dissolved oxygen into the sol of a higher hydroxide, ferric hydroxide sol being formed under the most favorable conditions, and probably ferroso-ferric hydroxide sol when the supply of oxygen is limited.

"4. The higher hydroxide sol now acts catalytically by oxidising metallic iron with relative rapidity and simultaneously undergoing reduction to a lower hydroxide sol, only to be oxidised again as oxygen from the air diffuses towards it."⁴³

318. Many of the phenomena of corrosion cannot, however, be explained without inquiring into the mechanism of this behavior of oxygen. In the first place it is necessary to recall a few very elementary principles. Iron is a solid and therefore can be dissolved from the surface only. Oxygen is a gas in the molecular state in the water and therefore if depleted at a given point, as on the surface of the iron, can be restored only by the slow process of diffusion from nearby places or by the arrival of a fresh portion of water. Both or only one of these methods can be in operation. A clear mental picture of

⁴³Any discussion of these theories would be out of place in these pages. Those who wish to read further should consult the following:

The Corrosion of Iron and Steel by J. N. Friend, Longmans, Green & Co. (1911).
Corrosion of Iron by L. C. Wilson, The Engineering Magazine Co. (1915).

The Preservation of Iron and Steel by A. S. Cushman, Bulletin No. 35, Office of Public Roads, U. S. Department of Agriculture.

The Causes and Prevention of Corrosion by Alan A. Pollitt, D. Van Nostrand Co. (1924.)

Sixth Report to the Corrosion Research Committee of the Institute of Metals. J. Inst. Metals, 28, 31 (1922) and in connection with this report, a long paper by Bancroft, The Electrolytic Theory of Corrosion, J. Phys. Chem. 28, 785 (1924).

the situation can be had by considering a piece of metal lying in the bottom of a vessel of water which stands undisturbed in a quiet place. The dissolved oxygen in the layer of water immediately in contact with the iron is soon exhausted and corrosion can then proceed only as more oxygen diffuses in or is carried in by convection or other currents. This has been the way in which in the past many laboratory experiments on corrosion have been conducted. The maintenance of constant conditions was all but hopeless and consequently such experiments gave discordant results. Let two variations of this case now be considered. In one an open vessel is used but the water is stirred. Fresh portions of oxygen-rich water are constantly brought into contact with the iron and the depleted oxygen is constantly being renewed from the air. Another experimenter, however, is more careful. He puts his piece of iron into water in a closed flask and keeps the water in motion by rotating the flask. There is a constant change of water on the surface of the iron but no renewal of oxygen from the outside. That experimenter will not get the same results as did the man with the beaker, so a third one will try. He also uses the closed flask method but happens to employ iron that is finely divided so that a very large surface of metal is exposed. His results will differ from all the others. These are all laboratory conditions and are cited because in the nature of things they are described most frequently in the literature, and when they are read it must be in the light of the rate at which oxygen reaches the surface of the iron.

319. The situation is the same in practice. Different users of the same water will report greatly differing experiences with corrosion. This may go so far that one man will report serious corrosion and another none at all. Perhaps the water is used in a steam boiler and one employs an open heater which drives out the dissolved oxygen. Perhaps it is so simple a matter as the corrosion of a pipe conveying the water. In one case the corrosion is many times faster than in the other, though it is the same water, same kind of metal in the pipe, and same size of pipe. It looks puzzling till one finds that the water is flowing faster through one pipe than through the other. The rates are such that in one case the flow of water is in a straight line. There is little or no mixing of the core of water in the center of the pipe with that in contact with the walls. The oxygen in this thin film of water in contact with the metal is soon exhausted and further corrosion must then depend upon the slow diffusion of oxygen from the center. In the other case the rate of flow is greater, great enough to become turbulent, thus causing a general mixing from center to outside of the pipe so that fresh water is constantly brought into contact with the metal. The result is far more rapid corrosion, due entirely to the fact that the difference in the rates of flow lay in the critical region near to that of straight line flow on one side and to turbulent flow on the other.

320. These hypothetical cases which are not only possible but also probable are given to show what a variety of corrosion phenomena can be explained by the behavior of the dissolved oxygen. The behavior of dissolved oxygen does not however exhaust all of the possibilities of the fundamental reaction. There can be differences in the concentration of hydrogen ions in the water and there can also be differences in the character of the metal.

Effect of Change in Hydrogen Ion Concentration

321. In distilled water of the highest purity the concentration of hydrogen ions is about 1 to 10,000,000. This is also about the concentration in naturally occurring water. In Ohio it is perhaps less, though probably not so low as 1 to 100,000,000. In modern nomenclature these values correspond to pH7 and pH8 respectively. The higher the pH value of a water the lower is its hydrogen ion concentration, or, the more acid the water the lower is its pH. Now, concentrations of one in ten million and one in a hundred million are very low, but one is ten times that of the other. This should mean that corrosion will go on ten times as fast in the one water as in the other. As a matter of fact, however, such is not the case, and therefore the mechanism of this part of the reaction must be explained. Experimental evidence seems to show that from about pH 11 to pH 5 the rate of corrosion is independent of the hydrogen ion concentration, though the higher of these concentrations is a million times that of the lower one. The only controlling factor in this range is the concentration of oxygen. The rate of corrosion is proportional to this. The reason for this independence of hydrogen ion concentration is explained by Wilson⁴⁴ in this way. Solution of the iron will not proceed unless the polarizing film of hydrogen is removed from the surface of the iron. This removal is accomplished by the dissolved oxygen which can do it only at the rate at which it reaches the metal. This is a slow rate because it depends upon the relatively slow rate of diffusion of the oxygen and the mechanical movement of the water. Other things being equal, this rate of approach of oxygen is, of course, proportional to the concentration of the oxygen and, consequently, as long as the molecular oxygen is slower than the hydrogen ions in reaching the iron, the rate of corrosion will be proportional to the concentration of the dissolved oxygen.

322. If the concentration of hydrogen ions becomes very low, Wilson puts it at about pH 11, at which value the water has caustic

⁴⁴R. E. Wilson, *The Mechanism of the Corrosion of Iron and Steel in Natural Waters and the Calculation of Specific Rates of Corrosion*, Ind. and Eng. Chem. 15, 129 (1923).

alkalinity, the action of the hydrogen becomes slower than the approach of the oxygen, and there will then be plenty of oxygen to remove the polarizing film as fast as it forms, with the consequence that the rate of corrosion in alkaline solutions should be proportional to the hydrogen ion concentration. This is shown by Speller and Texter⁴⁵ and by Whitman, Russell, and Altieri⁴⁶ to be at least approximately true but only during the first half hour or so of contact of the clean iron with the alkaline water. After this initial period the rate of corrosion remains constant probably because of the formation of a protective coating on the iron. In the alkaline region therefore the effect of a change in hydrogen ion concentration is, as a practical problem, purely one of the relation of this change to the formation of a protective coating on the iron. This point will be discussed below. Earlier investigations⁴⁷ had apparently shown that there was a concentration of alkali at which the rate of corrosion was a maximum. This, however, has not been confirmed by later studies in which the concentrations of oxygen and carbon dioxide were considered as factors.

323. There is also the case in which the concentration of the hydrogen ions is high, about pH 4, at which point the water begins to show acidity to methyl orange, in other words, is acid. Under such conditions the rate of formation of hydrogen is so rapid that the polarizing film is destroyed by the escape of the hydrogen as a gas. Oxygen is not needed to get rid of it and consequently from pH 4 and on to greater acidities the rate of corrosion is proportional to the hydrogen ion concentration.

According to Whitman, Russell, Welling, and J. D. Cochrane, Jr.,⁴⁸ there is nevertheless a marked depolarizing effect of oxygen even in the action of strong acids on steel, that is, the steel dissolved much faster if oxygen was present in the solution than if it was absent.

324. Practical men need not, however, worry over these two conditions. Natural water, even over-softened water or water dosed with alum is not likely to have a pH value higher than 11 or one of 4 or lower. Almost without exception natural waters have a pH of about 7 and treatment of various sorts does not change it more than one or two pH values on either side. Natural water is in fact a kind of buffer solution, that is, it resists any attempt to change its reaction by adding either alkali or acid in small amounts. The statement therefore still holds, that corrosion is proportional to the concentration of dissolved oxygen; but at this point should now be added the qualifying statement, *if the water is acting on bare iron*. Iron more or less coated by deposits from the water is a condition to be discussed later.

⁴⁵Ind. and Eng. Chem. 16, 393 (1924).

⁴⁶Ind. and Eng. Chem. 16, 665 (1924).

⁴⁷Lyon, J. Am. Soc. Naval Eng. 34, 845 (1912).

⁴⁸Ind. and Eng. Chem. 15, 672 (1923).

Effect of Character of the Metal

325. The fourth and last member of the equation is the iron itself. Its concentration cannot be changed because it is a solid and in a practical installation even the extent of the surface cannot be changed to any great degree; therefore, there remains only the possibility of changing the structure of the iron itself. This is a logical way of attacking the problem of corrosion and accordingly many attempts have been made to produce non-corroding alloys of iron. Some of these have been very successful, as for example the well-known monel metal and duriron. Attempts have also been made to reduce the corrodibility of steel by adding to it small amounts of other substances and among these efforts the effect of copper has provoked more discussion and perhaps greater difference of opinion than all of the others combined. So far as the author has found, however, no service experiments with water or steam pipes or with boiler tubes thus alloyed with copper have been recorded. The data at hand bear mostly upon corrosion caused by exposure to the weather. Finally, it is interesting to note that great claims are made for very pure iron as a non-corroding material and that such iron has been on the market for years. The outstanding question, however, as to the effect of the composition of the iron upon its corrodibility is the one of the relative merits of wrought iron and steel. This deserves special discussion.

Wrought Iron vs. Steel

326. There is a strong belief among steam engineers that wrought iron withstands the corrosive action of water better than steel, but a study of the literature of corrosion does not confirm this belief.

327. Friend⁴⁹ in his book on corrosion devotes a chapter to the relative rates of the corrosion of wrought iron and steel. Numerous series of experiments are cited and discussed. The final conclusion is summed up in the following, quoted from page 286: "It would appear therefore that when everything has been taken into consideration there is practically nothing to choose between wrought iron and steel as at present manufactured."

328. Wilson⁵⁰ in a more recent book on corrosion also has a chapter on the question and reaches the same conclusion as Friend.

329. A very recent book on corrosion, that of Pollitt,⁵¹ does not accord the question the dignity of a chapter but points out that each type of ferrous material has its proper use and concludes as follows:

⁴⁹The Corrosion of Iron and Steel by J. Newton Friend, Longmans, Green & Co. (1911).

⁵⁰The Corrosion of Iron by L. C. Wilson, The Eng. Magazine Co., New York (1915).

⁵¹The Causes and Prevention of Corrosion by Alan A. Pollitt, D. Van Nostrand (1924).

"If the results of reasonably large scale field tests, made under actual service conditions, are consulted together with the records of practical experience in the choice of material for a specific purpose, it will generally be found that, when employed in their proper spheres, so to speak, there is little to choose between the varieties of iron or steel as regards their relative corrodibilities." Pollitt emphasizes the importance of selecting the best material for a given use and quotes as follows from a paper by Friend in the Transactions of the Faraday Society, Vol. XI, 1915, "Our task therefore resolves itself into a wider problem, not so much whether iron is better than steel or vice versa but rather which is the best variety of iron or steel for any particular purpose."

330. The only experimental evidence on the relative corrodibility of wrought iron and steel that will be offered here is the work of Speller and Knowland.⁵²

Wrought iron and steel pipes were connected in series in a hot water heating system. The experiment began October 25, 1916, and continued till December 24, 1917—over a year. Analyses of the various steels and wrought irons were made and at the conclusion of the test the pits were measured. The final examination and report was made by J. O. Handy of the Pittsburgh Testing Laboratory from whose report the following paragraph is taken: "These measurements when summarized show no significant differences in the depth or extent of pitting between the steel and iron pipe. The slight differences shown are in some cases in favor of the wrought iron and in others in favor of the steel."

Spontaneous Formation of Protective Coatings

331. A discussion of the mechanism of corrosion would not be complete without mention of the possibility of the formation of protective coatings. Such coatings might result from properties inherent in the metal, as for example, if the impurities were left on the surface after the solution of the iron; or from the products of the reactions, for example, if the ferrous hydroxide of the fundamental reaction or the ferric hydroxide resulting from the action of the dissolved oxygen should remain as a film on the iron; and finally, in the practical situation in which natural water with its variety of dissolved and suspended matter is concerned, there is the possibility of coatings from these constituents. Of this third possibility there can be no doubt.

332. Natural waters do at times furnish protective coatings. True, the waters frequently overdo the matter and coat the pipes or boiler tubes too generously and the coating is then called scale and cursed for being an expense and trouble. Scale is nevertheless a protective coating deposited by the water itself, and when it can be con-

⁵²Tr. Am. Soc. Heat. and Vent. Eng. 24, 217 (1918).

trolled, is one of the simplest methods of reducing corrosion. This point is just beginning to gain recognition and consequently not much at present is known about it. Reference has been made to scale. There is also some reason to think that colloidal (slimy) coatings consisting in part of organic matter also constitute protective coatings deposited by certain waters. This has suggested the addition of colloidal material to water in order to produce protective coatings and it can be said that experiments begun by the Research Department of the National Tube Company and continued at Mellon Institute have shown that much can be accomplished in this way by the use of silicate of sodium.

333. One interesting case of the reduction of corrosion by causing the water to form a protective coating is given by Baylis.⁵³ The municipal supply of Baltimore, Md., after purification was corrosive and gave "red water." Baylis found that by adding lime so that the pH was increased to 8.5 or 9 the corrosion was practically eliminated. One's first impression would naturally be that the effect was due to the increase in alkalinity of the water. According to the theory, however, the small change in hydrogen ion concentration indicated should not affect the corrosion. What undoubtedly happened, as Baylis points out, was that this change in the hydrogen ion concentration of the water caused a thin layer of calcium carbonate to be deposited as a protective coating. Changing the pH value of waters will probably become a means of controlling deposits in the future.

334. Evidence is also at hand for the belief that the products of the main reactions of corrosion, the ferrous and ferric hydroxides, particularly the latter, form films over the iron and thus greatly retard the further action of the water. Speller and Texter⁵⁴ in their study of the corrosion of steel in alkaline solutions found that at 150° F. the rate of corrosion in alkaline water decreased rapidly for about an hour and then remained constant. They attribute this behavior to the formation of a film of ferric hydroxide. Their first experiments had been made with Pittsburgh city water and they then supposed that the protective coating consisted of material deposited from that water. A subsequent run, however, with distilled water and sodium hydroxide, gave the same result, and they therefore felt justified in assuming that a coating of ferric hydroxide was formed. Whitman, Russell, and Altieri⁵⁵ working on the effect of varying hydrogen ion concentration on the underwater corrosion of steel found the same effect and came to the same conclusion, namely, that a protective coating was formed. These investigators report an interesting experiment with carbonic acid which may be of importance in studying the formation of carbonate scales. They found that carbonic acid at a pH value of about 5.4 was as corrosive

⁵³J. R. Baylis, *J. Am. Water Works Assoc.* 10, 385.

⁵⁴*Ind. and Eng. Chem.* 16, 393 (1924).

⁵⁵*Ind. and Eng. Chem.* 16, 665, (1924).

as hydrochloric acid at a pH of 4.1. Since in this comparison the hydrogen ion concentration of the water containing the hydrochloric acid was more than ten times that of the water with the carbonic acid, the situation at first seems anomalous. The authors' explanation is, however, plausible and probably correct. They point out that at pH 5.4 carbonic acid is only 6 per cent dissociated and that there is therefore present 15 parts of undissociated acid for each part of the dissociated. This means that as soon as the dissociated part has acted in neutralizing the alkaline protective film next to the metal the undissociated part progressively dissociates and continues to destroy the film. Since at such low concentrations hydrochloric acid is practically completely dissociated it is seen that there will have to be theoretically 16 times as much of it present as of carbonic acid to have the same effect in neutralizing an alkaline film. Calculation shows that a hydrogen ion concentration 16 times greater than that represented by pH 5.4 is pH 4.2 which is most excellent agreement with the experimental value 4.1. Without the assumption of a protective film of an alkaline nature it would be difficult to explain this behavior of carbonic and hydrochloric acids.

335. No discussion has been found of the possibility of protective coatings resulting from impurities in the iron being left on the surface when the iron itself has been corroded away. Such a hypothesis has, however, been suggested to the author by one of his colleagues, Professor D. J. Demorest, to account for the well-known resistance to corrosion of cast iron. Professor Demorest points out that 15 to 20 per cent of the volume (not weight) of cast iron consists of graphite and silicon. This is because of the low densities of these substances. A very superficial corrosion of the iron would therefore leave on the surface a layer of graphite mixed with silica, the silica resulting from the oxidation of the silicon. Both graphite and silica are highly resistant to corrosion and would therefore act as a protective coating.

336. As a concluding paragraph to this presentation of the general aspects of corrosion of iron and steel by water the author would like to refer his readers to two short papers of a speculative and philosophic nature, Problems of Corrosion, by B. D. Saklatwalla,⁵⁶ and The Mechanism of Corrosion, by John Johnston.⁵⁷

Some Miscellaneous Factors in Corrosion

Temperature

337. As would be expected, the rate of corrosion increases with increase of temperature. Calcott⁵⁸ investigated the range between 20°

⁵⁶Ind. and Eng. Chem. 15, 39 (1923).

⁵⁷Ind. and Eng. Chem. 15, 903 (1923).

⁵⁸Ind. and Eng. Chem. 15, 677 (1923).

and 100° and says that the rate of corrosion changes from 1 to 3 per cent per degree within this range. No data have been found on the effects of the temperatures reached in high pressure boilers.

338. It should be pointed out, however, that in practical situations dealing with natural waters the effect of a temperature increase may be very complex. The specific rate of corrosion is undoubtedly always increased but in most cases other factors are also changed. Salts in solution may be hydrolyzed with an accompanying increase in hydrogen ion concentration so great that the rate of corrosion will be increased for that reason. On the other hand, if the water is not in a closed system much of its dissolved oxygen will escape and consequently the rate of corrosion will be lowered. In studying any set of results then the reader must remember that unless all of the factors have been considered the measurements recorded as the effect of temperature change are really the algebraic sums of a number of effects.

Velocity

339. Conflicting statements are to be found on the relation between the rate at which water flows over iron and the rate at which that iron corrodes. It is a practical problem wherever water is conveyed in iron pipes and therefore merits some discussion. According to Friend⁵⁹ corrosion at very low velocities of water movement at first increases with the velocity of flow and then falls off to a minimum rate at about two miles an hour, from which it again rises. In other words, Friend holds that there is an optimum velocity at which the rate of corrosion is least. Wilson⁶⁰ and Speller and Kendall⁶¹ dispute the statements of Friend and say that they found no minimum rate of corrosion with an increasing rate of flow of the water. Whitman⁶² and others investigated the effect of velocity on the rate of corrosion of steel in sulfuric acid from about 0.005N to 5N and found that with the exception of the 0.005N acid corrosion at first fell off with increasing velocity and then increased. In other words, they found that there was a certain velocity at which corrosion was a minimum. Since, however, the hydrogen ion concentrations of the acids employed were far beyond that of any natural water further details will not be given.

340. Speller and Kendall working with natural water flowing through pipes found that as the velocity of the water increased, the rate of corrosion increased faster at some velocities than others. They

⁵⁹In addition to the electrolytic theory of corrosion three others have been advanced. See also Heyn and Bauer *Mittheilungen Könlichen Materialprüfungsamt*, Berlin 28 (1910).

⁶⁰R. E. Wilson. *The Mechanism of the Corrosion of Iron and Steel in Natural Waters and the Calculation of Specific Rates of Corrosion*. *Ind. and Eng. Chem.* 15, 129 (1923).

⁶¹*Ind. and Eng. Chem.* 15, 134 (1923).

⁶²*Ind. and Eng. Chem.* 15, 672 (1923).

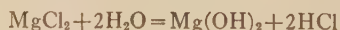
account for this on the basis of the transition from straight line to turbulent flow of the water. At low velocities the water flows in a straight line, that is, there is little or no mixing of the layer next to the metal with that in the center of the pipe. The rate of corrosion is therefore slow because it will depend largely upon the rate of diffusion of oxygen into the outside layer. As the flow becomes turbulent this outside layer is disturbed more and more with the result that more and more oxygen reaches the iron. Corrosion will therefore increase rapidly through this transitional period. Finally when the flow of the water with increasing velocity becomes completely turbulent the rate of corrosion will become constant or nearly so. Erosion of the protective surface layer may of course begin at high velocity.

Salts in Solution

341. Salts in solution in a water usually affect its corrosive action, generally in the sense that, beginning with low concentrations an increase in salt concentration increases corrosion till a maximum is reached after which corrosion falls off as the salts increase. Friend in his book and in Carnegie Scholarship Memoirs, Vol. 2, (1922) discusses these points. The situations that may result, are, however, so complex and at best are as yet so little understood that they will not be discussed further than in the special points below.

342. Salts of weak bases and of weak acids hydrolyze and thus either increase or decrease the normal hydrogen ion concentration of the water. This is said by some to have a marked effect on corrosion. It is doubtful, however, in view of the considerations brought forward under magnesium chloride below. Salts in solution increase the conductivity of the water and should therefore, according to the electrolytic theory, increase corrosion. Oxygen is not as soluble in a salt solution as in pure water. This should decrease corrosion. The effect of dissolved salts on the protective coating (318) has as yet been but little studied.

343. Magnesium chloride demands special consideration. Few statements occur oftener than that this salt is a potent cause of corrosion, the reason given being the fact that in hot water it hydrolyzes with the formation of hydrochloric acid and magnesium hydroxide according to the reaction,



The magnesium hydroxide is insoluble and precipitates leaving the acid in solution. Ost⁶³ has studied this situation and says that though a 40 to 50 per cent solution of magnesium chloride will give off hydrochloric acid at 106° C. a dilute solution will not do it even at 183°

⁶³Z. fur Angew. Ch. (Aufsatzteil) 34, 396.

C., 150 pounds pressure. Ost's experiments at atmospheric pressure were repeated in the author's laboratory and his results confirmed.⁶⁴

Hydrogen sulfide ("Sulfur" water)

344. Waters containing hydrogen sulfide, of which Ohio has many examples, are very corrosive even in the cold. Since hydrogen sulfide is a strong reducing agent and will react with the dissolved oxygen in water it might at first be supposed that it would inhibit corrosion. Possibly it owes its action to an increase in the hydrogen ion concentration and the very great insolubility of the sulfide of iron. It is also possible that the sulfide of iron does not adhere to the metal to form a protective coating.

Pitting

345. Corrosion of iron and steel is not uniform but takes place in small areas in which the action is so great that holes or depressions are produced. These are called pits. This inequality of corrosive action is most unfortunate because it results in penetration long before any considerable amount of the iron has been dissolved. According to the electrolytic theory pitting is due to inequalities in the composition of the metal which makes some portions more electropositive than others. A number of tiny batteries are thus in effect created. The current flows from one spot on the iron through the water (the electrolyte of the battery) to another spot and then through the metal to the first spot. This not only causes one place to dissolve faster than the adjacent areas but it actually protects the adjacent areas from corrosion.

346. The pits are not, as might at first be expected, uniformly distributed over the surface of the iron but are more numerous at those places where the water is richer in oxygen or at a higher temperature or where the metal itself is more susceptible to corrosion, for example, where it has been subjected to mechanical strain as at bends, around rivets, etc., or near where it is in contact with a metal lower in the electromotive series.⁶⁶ There is also some reason to believe that even in under-water corrosion a bit of rust depositing on the iron may become the starting point of a pit.

Methods of Expressing Rates of Corrosion

347. One of the earliest and, from certain aspects, still one of the best ways of expressing a rate of corrosion is to give it as the loss in weight in unit time from a unit area of the exposed metal. Since, however, such effects of corrosion as the weakening of a structural piece or

⁶⁴An unpublished senior thesis by G. H. Mutersbaugh.

⁶⁶Whitman and Russell, *Ind. and Eng. Chem.* 16, 276 (1924).

the development of leaks in a pipe are more important from a practical standpoint than the mere loss of so many pounds of material, it is often better to calculate corrosion rates in such a way as to indicate at least roughly the serviceable life of the metal in use. Calcott⁶⁷ gives such a calculation as follows:

W = loss in weight in grams of test piece during second 48 hours immersion.

A = area of test piece in square inches.

S = density of metal in grams per cubic centimeter.

t = time of exposure in hours.

C = rate of chemical corrosion expressed as inches penetration per month.

On introducing the necessary factors for giving the number of hours in a month and for transforming the metric dimensions to inches the following equation is obtained:

$$C = \frac{24 \times 30 \times W}{(2.54)^3 A S t} = 43.9 \frac{W}{A S t}$$

According to Calcott, if C has a value less than 0.01 in. the corrosion rate is moderate.

348. This equation, however, does not take into account the well-known fact that corrosion is not uniform but occurs mostly in limited areas giving rise to the familiar pitting. Since the rate of formation of the deepest pit in many cases determines the useful life of a piece, some way of bringing this into the calculation must be found. Calcott does this by grinding down the test piece of metal till all of the pits have been removed. The loss in weight caused by this grinding is called P and is added to W above. The equation then gives the rate of penetration due to both the uniform and pitting corrosion. This Calcott expresses by D so that the equation is then,

$$D = 43.9 \frac{W + P}{A S t}$$

349. It will be observed that the only variable in these equations which does not represent a change in the metal itself is the time of exposure. Variations in the temperature, concentration of dissolved oxygen, pH value, etc., of the water must each be expressed by the different values of C or D in as many different equations. This is perhaps sufficient excepting for the dissolved oxygen. It has been shown above that the rate of corrosion by water is proportional to its oxygen content, and since this is not constant for any given water, but varies according to the conditions under which the water is used, it is well to treat it as a separate factor which is not necessarily a property of the water. Wilson⁶⁸ first called attention to this and suggested calculating the "specific rate of corrosion in terms of loss of weight per unit area per unit time per unit concentration of oxygen." For con-

⁶⁷Ind. and Eng. Chem. 15, 677 (1923).

⁶⁸R. E. Wilson, Ind. and Eng. Chem. 15, 129 (1923).

venient units Wilson suggests that the specific corrosion, K , be expressed as milligrams of loss per square centimeter per year per cubic centimeter oxygen in one liter of water. These units, he says, will give figures of a convenient order of magnitude. Wilson gives various equations for special conditions, and in the same number of *Ind. and Eng. Chemistry*, page 134, Speller and Kendall have an article on corrosion in which they use the Wilson method of calculation.

Prevention of Corrosion

350. Owing to the cost of non-corrosive alloys and the failure to find artificial coatings for iron and steel which will withstand under-water service conditions, particularly at high temperatures, the practical solutions of the problems of corrosion all consist in some modification of the action of the water. The electrolytic theory at once offers three suggestions: (1) maintain the hydrogen ion concentration of the water below the corrosive limit; (2) remove the dissolved oxygen from the water; (3) impress a counter electromotive force higher than that resulting from the solution of the iron. All of these methods are effective and all are in commercial use. The best method to employ for a given situation is determined by the general and specific conditions of that situation.

351. Though no hard and fast lines can be drawn the general conditions of corrosion can be classified as, (1) large scale, cold water corrosion such as sometimes occurs in the mains and service pipes of a city supply, and (2) hot water corrosion such as takes place in hot water heating systems, steam boilers, etc.

Maintaining a Low Hydrogen Ion Concentration to Prevent Corrosion

352. The phrase, maintaining a low concentration, is used advisedly rather than the one that would occur at first, namely, reducing the concentration, because it is particularly true of hydrogen ions that it is easier to change their concentration than it is to maintain a given concentration. In hot water systems and especially in high pressure steam boilers reactions between the water and dissolved salts are constantly going on in ways that tend to raise or lower the hydrogen ion concentration. As the water evaporates and the concentration of dissolved salts increases, the rates of these reactions change or new reactions begin, and it is therefore unlikely, with most waters at least, that the hydrogen ion concentration could be kept below a given value without using excessive amounts of alkali. In cold water such reactions either do not exist or the changes proceed so slowly that equilibrium can be maintained for long periods of time, and therefore the addition of small amounts of lime or other alkali will keep the water from corroding.

353. It must be said, however, in spite of the electrolytic theory, that the mechanism of the effect on corrosion of lowering the hydrogen ion concentration seems to be the formation of a protective coating rather than a mere reduction of the solvent action of the water. Speller and Texter⁶⁹ for example say, on the basis of their experiments, that "the initial rate of corrosion is nearly independent of the alkalinity of the water but that at a temperature of 150° F. the rate of corrosion in alkaline water rapidly decreases for an hour or so (depending on the temperature) until a protective film of ferric hydroxide has been built up and a state of equilibrium established. At this point alkalinity has the well-known inhibiting effect which has been pointed out by other investigators." Whitman, Russell, and Altieri⁷⁰ confirm the results of Speller and Texter. Reference has already been made (333) to the simple way in which Baylis stopped the corrosion of the Baltimore city mains by lowering the hydrogen ion concentration of the water with lime. The effectiveness of this scheme undoubtedly lies in the indirect effect on the formation of a protective coating. From a practical standpoint it of course matters little whether lowering the hydrogen ion concentration reduces the solution of the iron or forms a protective coating over the iron. The important point is that corrosion can be controlled in this way. It is also obvious that it is an ideal way for solving the large-scale corrosion problem of a city's water mains or that of a long conduit.

Removal of Dissolved Oxygen to Prevent Corrosion⁷¹

354. Water at ordinary temperatures contains about 10 cc. of dissolved oxygen per liter. West⁷² states that a reduction of the oxygen to 0.5 to 0.75 cc. per liter will arrest corrosion under certain conditions, but in the feed pipes, pumps, and steel tube economizers of the modern high pressure power plant the oxygen should be as low as 0.2 cc. per liter. Speller and Knowland⁷³ show that 2.18 cc. of oxygen per liter produces serious corrosion in a hot water heating system in a year.

355. The actual removal of the dissolved oxygen in a water can be accomplished by (1) heating, or better boiling, the water either at atmospheric or reduced pressure; (2) by subjecting the water to reduced pressure without heat; (3) chemically, by putting something into the water to combine with the oxygen. In practice all three methods may be combined, though usually (1) and (2) are used together or (3) by itself.

⁶⁹Ind. and Eng. Chem. 16, 393 (1924).

⁷⁰Ind. and Eng. Chem. 16, 665 (1924).

⁷¹See 301 for a discussion of the role of oxygen in corrosion.

⁷²Ind. and Eng. Chem. 14, 801 (1922).

⁷³Tr. Am. Soc. Heat. & Vent. Eng. 24, 226 (1918). Also in Eng. and Min. J. 107, 480.

356. The chemical method on account of its simplicity will probably come to be the preferred one for small plants. Scrap iron in some form or some more readily corroded alloy of iron is used as the deoxidizing or deactivating reagent to combine with the oxygen. Kestner⁷⁴ describes an apparatus consisting of a chamber filled with pieces of an alloy of iron and manganese. Boiler water in passing over this metal corroded it and thus lost its dissolved oxygen. The following quotations from Kestner's article suggest several important engineering details.

357. "In commercial appliances, when the coating of oxide becomes very thick, the removal of the oxygen may become considerably slower, but under the most unfavorable conditions, water leaving such apparatus is found to contain less than 0.5 cc. of oxygen per liter."

Kestner observed that if the rust deposited on the scrap iron as the result of corrosion were allowed to remain at rest for a day it changed its color from red to a greenish black, due to the reduction of ferric hydroxide by the iron. This product was easily removed by washing.

358. "The Kestner apparatus consists of a column of iron turnings placed between two filters with an intake and outlet for the water at each end of the apparatus, in such manner that the direction of flow of the water can be reversed at regular intervals, and an arrangement for allowing steam to be admitted at the base for cleaning.

359. "The column of turnings is of such quantity that one-half only is in action and that the gases are removed when the water has reached half the height. At the end of the day the direction of flow is reversed. The consumption of iron turnings varies from 1 to 3 grams per cubic meter of water."

At the rate of 3 grams per cubic meter of water 1 pound of scrap would deoxidize 40,000 gallons of water.

360. The prevention of corrosion in hot water heating systems was accomplished by Speller and Knowland⁷⁵ by causing the water to circulate through a chamber filled with expanded steel lathing. This gave a large surface of contact for corrosion and consequently used up the oxygen dissolved in the water. A report from this equipment after over two years of service showed no evidence of pitting in the hot water pipes which for experimental purposes consisted of alternate sections of steel and wrought iron. Similar steel and iron pipes in a system using the same water but without passing it through the chamber for removing oxygen suffered serious corrosion in one year (330).

361. Speller and Knowland raise the question as to how long the expanded metal lath in the corrosion chamber will last, but say frankly that it can not be answered till it has been longer in operation. They point out the obvious advantage of the scheme in the following sen-

⁷⁴J. Soc. Chem. Ind. 40, 67 (1921).

⁷⁵Tr. Am. Soc. Heat. and Vent. Eng. 24, 217 (1918). Also, Abatement of Corrosion in Central Heating Systems, Bureau of Mines Technical Paper 236.

tence: "It is much cheaper and vastly more convenient to corrode away a hundred pounds of sheet metal in the basement than the same weight of piping in miscellaneous locations throughout the house."

362. The mechanical method of removing the dissolved air consists in allowing the water to spray into a chamber in which reduced pressure is maintained by means of an air pump. The interior equipment of the chamber may be a series of pans over which the water can cascade to the bottom. This combination of spraying and exposure in thin layers affords the best conditions for the escape of any dissolved gas.

363. McDermet⁷⁶ describes such an installation for the mechanical removal of dissolved air. The apparatus was made of cast iron and non-corroding bronzes and was so arranged that water at 212° F. was sprayed into a vacuum chamber in which the pressure was kept at about 20 inches of mercury. Cascade pans completed the equipment. Under these conditions explosive boiling took place and the air was pumped out. Steam that followed the air was condensed. By this means dissolved oxygen was reduced nearly to zero. McDermet gives no comparative figures on corrosion but he does state the interesting fact that the air-free steam from this deaerated water conducts about 20 per cent better than steam with air, thus greatly increasing the efficiency of the condensers. This is a remarkably large incidental effect and note should therefore be made of it as an advantage over the chemical method which removes the oxygen only of the dissolved air in the water.

364. West⁷⁷ describes several forms of mechanical and chemical deoxidizers one of which combines the mechanical and chemical principles. He makes the point that it is economical to remove the bulk of the dissolved gases by mechanical means and then destroy the last portions of the oxygen by passing the water through a chamber filled with scrap iron.

Electrical Methods of Preventing Corrosion

365. One of the commonest attempts to prevent corrosion in steam boilers is the use of metallic zinc in electrical contact with the iron. Because zinc has a greater tendency to dissolve than iron a counter electromotive force is set up stronger than any that could be produced by the dissolving of the iron and therefore the iron does not corrode. Theoretically such a use of zinc is entirely correct, but it is extremely doubtful whether it performs the miracles sometimes attributed to it. Pollitt⁷⁸ says that zinc is a fetish with some engineers. In practice it is difficult to space it properly in a boiler and sometimes it behaves in

⁷⁶Mech. Eng. 42, 273 (1920).

⁷⁷Ind. and Eng. Chem. 14, 604 (1922).

⁷⁸The Causes and Prevention of Corrosion by Alan A. Pollitt, D. Van Nostrand (1924).

an erratic way even to the extent of reversing its polarity. At best the protection afforded by a piece of zinc is not indefinite, but extends only a few feet, as shown by the rule followed in marine boiler practice, namely, allow a square foot of zinc for each 50 square feet of boiler surface.

366. Since the effect of zinc on corrosion is purely one of counter electromotive force, it follows that such a force produced outside the boiler will serve as well. This is done in the Cumberland⁷⁹ process. Large iron electrodes connected with the positive pole of a generator are placed in various positions in the water inside the boiler and the boiler itself is connected with the negative pole. The electrodes must of course be insulated from the boiler. A small D. C. type of generator can be employed as the source of counter E. M. F. Iron dissolves from the easily renewable electrodes but none can dissolve from the boiler because of the strong, counter electromotive force of the generated current. This system has been in use for years in various power plants in England but does not seem to be much in evidence in this country. It should be noted that such a scheme is a general preventive of corrosion of metals and is not confined to the corrosion of iron and steel.

367. Cumberland makes the interesting statement that the regular working of his electrolytic system has the effect of loosening any hard scale that was in the boilers and of preventing its further formation. This means of course not that no scale is formed but merely that it does not adhere to the boiler but precipitates as a sludge. Cumberland gives no reason for this interesting phenomenon, but it is evidently the effect of the hydrogen gas given off from the surface of the iron. Gebhardt⁸⁰ gives this as the reason for the similar effect of metallic zinc in a boiler.

368. Those who are interested in laboratory experiments on the prevention of corrosion by electrolytic methods should refer to the United States Bureau of Mines Technical Paper No. 15 by Clement and Walker.

The author desires also to refer his readers to the Corrosion Symposium, Ind. and Eng. Chem. 17, 335 (1925). The series of papers in this symposium appeared too late to be embodied in this Bulletin.

⁷⁹Tr. Faraday Soc. 11, 183 (1916).

⁸⁰Gebhardt, G. F., Steam Power Plant Engineering, John Wiley & Sons, N. Y., 1917, page 573.

CHAPTER X

FOAMING AND PRIMING⁸¹

Present Knowledge of Foaming and Priming

369. Any one who wishes to learn what relation exists between the water in a steam boiler and the foaming or priming of that boiler will quickly reach the conclusion of Stromeyer⁸² who wrote in 1893: "*Priming. Information on this subject is as yet almost nonexistent.*" Eighteen years later Stabler⁸³ evidently felt that little information had been added for he began his section on foaming and priming with the statement that they "are probably the least understood of boiler phenomena." The books and papers on boilers contain many statements about foaming and priming but offer little or no experimental evidence in support of many of them. The situation is also complicated by much confusion in the use of terms and finally there has as yet been no general chemical theory of foaming. (The contrast in this respect to the problem of corrosion is marked.) It seems worth while therefore to clear up some of the confusion by summarizing briefly the present state of knowledge on this subject and to offer some new experimental evidence and a tentative physico-chemical theory.'

Meaning of the Terms "Foaming" and "Priming"

370. An examination of boiler water papers shows that one or more of three fairly distinct mental pictures of phenomena inside the boiler were in the minds of the writers when they used the terms foaming and priming. (1) The formation of foam on the surface of the water. This foam may range in thickness from a layer barely covering the surface to a mass that fills the steam space above the water. In the latter case the liquid films around the bubbles would be drawn into the steam pipe and wet steam would result. (2) Another phenomenon evidently in the minds of certain writers is merely rapid ebullition with the consequent projection of droplets or even slugs of water into the steam pipe. This could happen without the appearance of foam as it is described above. (3) A third situation partakes both of the properties and appearance of foam and of violent ebullition. The boiling is of such a character that the whole mass of water from the bottom up is full of fine steam

⁸¹Adapted from a paper by the author on foaming of boiler water. *Ind. and Eng. Chem.* 16, 1121 (1924).

⁸²C. E. Stromeyer, *Marine Boilers*, p. 42 (1893).

⁸³Herman Stabler, *The Industrial Applications of Water Analysis*, *Eng. News*, 60, 355 (1908), and U. S. Geological Survey, *Water Supply Paper* 274, p. 171 (1911).

bubbles with the consequence that the interior of the boiler is filled and of course much water passes out with the steam.

371. It should be emphasized perhaps that the three situations pictured above are not necessarily descriptions based upon actual observations made of steam boilers in operation. If such actual observations have been made the writer has failed to find the record of them. They are to be looked upon more as reasonable suppositions by men of experience with steam boilers and who have undoubtedly observed analogous situations in glass flasks or open metal vessels. Finally, some writers in their paragraphs or sections on foaming and priming evidently have no picture in mind of what goes on inside the boiler. They simply use the terms as meaning any entrainment of water by the steam.

372. When now one seeks the connection between these phenomena and the names foaming or priming as applied to them, utter confusion is found. Some authors use the terms interchangeably. Some call a foam on the surface priming and others describe one of the other situations as foaming. Indeed it can be said that a reader of any given book or paper will not know what is meant unless the writer defines his terms.

Causes of Foaming and Priming

373. The causes of foaming and priming as given in boiler water papers fall under two general heads, physical and chemical. Under the physical causes the design and operation of the boiler are outstanding. The more complex the interior, that is, the more of a maze of tubes, stay-bolts, etc. there is in the boiler, the more likely is it to foam (prime). It is also evident that other conditions being the same the smaller the steam space above the water the more likely is water to be carried out. If while in use the boiler is moved about rapidly, as is the case with the railroad locomotive, the extra agitation will promote foaming (priming).

374. Violent ebullition for a few seconds may result from the sudden evolution of steam following a period of superheating of the water, analogous to the familiar "bumping" of liquids in the laboratory. A similar effect would be produced by the loosening of a sheet of scale which would thus bring water into contact with almost red hot metal. The sudden introduction of solid matter entering with the feed water or produced by the loosening of scale also causes a violent ebullition for a few seconds, and a rapid opening of the steam valve by causing a momentary lowering of the pressure has the same effect.

375. There is some difference of opinion on the relation of steam pressure to foaming but the majority seem to hold that high pressure boilers foam less than low pressure ones. Such a statement seems logical because a given weight of steam occupies less space the higher

the pressure it is under. This must be considered, however, as applying only to situations 1 and 3 above. (370)

376. The available information about the chemical causes of foaming may be classified under (1) substances that cause foaming and (2) physico-chemical explanations of the phenomenon. The offending substances are listed under such general terms as "organic matter," "impurities," "oily matter," "soap and soapy substances," "saline matter," "alkalis," and "suspended solids." Sodium salts seem to be the only definite chemical substances to which foaming and priming are generally attributed, but the writer has not been able to find a record of any experiments which show that sodium salts alone are the cause of the trouble. The belief has unquestionably originated from the fact that in the great majority of waters sodium salts are the only ones that concentrate in the boiler. Others that are present in any quantity, such as calcium and magnesium compounds, precipitate for the most part.

377. Although the original evidence for the effect of sodium salts cannot be found there are a number of articles that offer experimental proof that sodium salts do not cause foaming (priming). In 1890 Lord Rayleigh⁸⁴ in an article on the theory of foams stated that he had found that even a strong salt (NaCl) solution did not foam much. Tatlock and Thompson⁸⁵ report a boiler which contained 16,000 parts per million of sodium carbonate, 2,100 of sodium hydroxide, and 13,000 of sodium sulfate "but showed no trace of priming." Koyl⁸⁶ also cites instances in which a high concentration of sodium salts was in a locomotive boiler water and yet no foaming resulted unless finely divided solid matter was also present.

378. Next to sodium salts finely divided solid matter is held responsible for foaming and priming and some go so far as to assert that solids are the only cause, barring of course occasional cases of soap or peculiar forms of organic matter in the water. Koyl in the papers cited above records some interesting laboratory and locomotive boiler experiments the purport of which can be given in the following quotation: "In the laboratory I have many times fed into boiling distilled water quantities of chemically pure sodium carbonate up to several hundred grains per gallon without producing any foaming effect. But if there is fed into boiling distilled water a fine insoluble powder such as calcium carbonate or magnesia alba the water will soon be foaming as vigorously as any one could wish."

379. In the second reference cited Koyl records some extensive experiments with locomotive boilers which did not foam with high sodium salts unless finely divided solid matter resulting from loosened

⁸⁴Chem. News, 52, 1 (1890).

⁸⁵J. Soc. Chem. Ind. 23, 428 (1904).

⁸⁶C. H. Koyl, (a) R. R. Gaz. 32, 663 (1900) and (b) 34, 423 (1902).

scale was present. He also cites an interesting case of a plausible though faulty judgment concerning the effect of softened water on foaming. On one part of the road the locomotive boilers did not foam though there was scaling due to the character of the water. When, however, these boilers were filled with softened water at a certain station they began to foam. This was blamed on the sodium salts in the softened water. It was proved, though, to be due to finely divided scale which was loosened by the new water. The method of proof was to use the treated water exclusively in several runs with a clean boiler over a long stretch of road. This was accomplished by hauling tank cars of the softened water. No trouble whatever was then experienced.

380. A comprehensive physico-chemical theory of boiler water foaming has as yet not appeared. Many writers it is true ascribe the phenomenon to the increase in the surface tension of the liquid brought about by the dissolved sodium salts but no one has sought to harmonize with this the evidence offered by Tatlock, Koyl, and others as cited above, which seems to show that foaming has no connection with the sodium salts; and no one has offered an explanation of the behavior of suspended solids in the boiler water.

381. Obviously a theory is needed that will harmonize the conflicting statements and, what is of much greater importance, will serve as a guide for research in this important field of industrial chemistry. The author therefore acting on the belief that even a poor theory is better than none at all, presents the one here. To avoid confusion it must be understood that this theory is intended to apply only to what may properly be called foaming, that is, the formation of a mass of bubbles or froth on the surface of the water.

A Physico-Chemical Theory of Foaming

382. Until quite recently no adequate presentation of the physical chemistry of foams has been available in English. Periodical literature also contains very little that deals with the theoretical side of the subject as reference to our *Decennial Index* and to the later volumes of *Chemical Abstracts* will show. Indeed the very first item under the word "foam" in the Index is such a discouraging cross reference that one hardly feels like turning over the page.⁸⁷ Bancroft,⁸⁸ however, has now given us the principles of the chemistry of foams⁸⁹ and on these

⁸⁷It would be a shame not to let every water enthusiast look up this reference for himself.

⁸⁸Bancroft, *Applied Colloid Chemistry, General Theory*, page 268 (1921). McGraw-Hill Book Company.

⁸⁹In the Fourth Report on Colloid Chemistry and its General and Industrial Applications, British Association for the Advancement of Science, page 263, is a most excellent paper by E. Edser on ore flotation, a part of which is given to a general discussion of foams.

there can be built a theory of boiler water foaming which is at least in agreement with recorded experience and which also will harmonize the conflicting statements that are found concerning the effect of sodium salts. Two paragraphs in Bancroft's book (p. 270) present the chemistry of foams so well that they are quoted here.

383. "To get a foam the only essential is that there shall be a distinct surface film, in other words, that the concentration in the surface layer shall differ perceptibly from that in the mass of the liquid. All true solutions will therefore foam if there is a marked change of surface tension with concentration, regardless whether the surface tension increases or decreases. All colloidal solutions will foam if the colloid concentrates in the interface or if it is driven away from the interface. To get a fairly permanent foam the surface film must either be sufficiently viscous in itself or must be stabilized in some way. This can be done by introducing a solid powder into the interface.

384. "Solutions of aqueous alcohol, acetic acid, sodium chloride, and sulphuric acid all foam when shaken; but the foam is instable. Soap solutions foam when shaken and the foam is, or may be, quite stable owing to the viscosity of the soap film. With saponin the surface film is even more stable. If we add to aqueous alcohol some substance like lycopodium powder which goes into the interface, we get a stabilized foam. We can do the same thing with aqueous acetic acid by adding lamp black. The presence of enough of a finely divided solid in the interface will make the film so viscous that the foam will be quite stable. Grease will help stabilize a foam in some cases and it has been claimed erroneously that the foaming of sulphuric acid solutions is due to grease."

385. On applying these principles to boiler water, it can be said that the fundamental condition of foaming is the presence of substances which concentrate either in the surface or in the mass of the water and thus change the surface tension. Whether there is an increase or a decrease makes no difference. If, however, these substances which change the surface tension do not at the same time have the property of making the films around the bubbles stable there will be no foam in a practical sense because the life of the bubbles will be too short. They will burst a moment after forming. It is necessary then to distinguish carefully between the two conditions for the formation of foam, (1) the presence of something which either by raising or lowering the surface tension of the liquid makes possible the formation of bubbles, and (2) the presence of something which by imparting viscosity to the films will stabilize them, that is, prevent them from bursting immediately after forming. This necessary viscosity can, of course, be produced by the same substance which changes the surface tension. Soap for example is such a substance and, undoubtedly, an occasional water is found in which the organic matter has this property, either as it enters the boiler

or after modification by the action of the superheated water. In the average boiler water, however, the change of the surface tension is brought about by dissolved sodium salts and the stabilization of the foam by finely divided solid matter. The presence of either one without the other is not sufficient to cause foaming.

386. The action of the particles of solid in stabilizing the foam appears to be purely mechanical. Edser⁹⁰ in his paper on ore flotation pictures the situation as follows: "Imagine a number of bubbles in the interior of a liquid, each bubble being coated with mineral particles. When these coated bubbles come into contact after rising through the liquid, the walls of each cell will consist of numerous solid particles held together by films of liquid." In flotation the solid particles are frequently the only stabilizing agent present. It must of course be emphasized that to stabilize a boiler water foam as well as that of a flotation process the solids must have the property of adhering to (being adsorbed on) the films. Flotation as a method of separation would be impossible if solids did not behave differently in this respect, and, it might be added, boiler foaming would be a rare occurrence were it not for the unfortunate circumstance that the solids usually present in a boiler have the property of adhering to the films around the steam bubbles.

387. Koyl⁹¹ gives the presence of finely divided solids as the cause of the phenomenon described above under (3) but merely states that each particle becomes a nucleus from which a stream of steam bubbles rises. It would not be too far-fetched to assume that the particles that act in this way have entrained a minute bubble of air or perhaps of carbon dioxide which then would serve as a permanent gas phase surface at which steam bubbles would form. The stabilizing effect of the finely divided solid matter would tend to hold such steam bubbles intact, that is, prevent them from coalescing. In this way the mass of the water would become filled with bubbles as Koyl describes.

Laboratory Experiments on Foaming

388. With the exception of Koyl no one seems to have performed any laboratory experiments on the production of foams in water solutions like those in steam boilers. This deficiency the author has attempted to remedy by having a rather extensive series of such experiments carried out.⁹² About 500 cc. of solutions of various substances, with and without the addition of finely divided solid matter, were boiled in glass flasks. The details of the experiments are given in the

⁹⁰Fourth Report on Colloid Chemistry, British Association for the Advancement of Science, page 263.

⁹¹C. H. Koyl, R. R. Gaz. 32, 663 (1900).

⁹²An unpublished Master's thesis by George L. Bush.

paper already referred to.⁹³ Only the general conclusions can be stated here.

389. Solutions of various compounds of calcium, magnesium, and sodium were boiled at pressures from 0.3 to 3.5 atmospheres, but in no case was a true foam produced. All of the substances, however, along with finely divided solid matter (385 and 386), gave foaming mixtures.

390. At least a hundred trials were made with various insoluble powders—pumice, sulfur, pyrolusite, bone black, lead sulfide, boiler scale, precipitated calcium carbonate, and limestone—in boiling distilled water, but no appreciable foaming was observed.^{93a}

Any of these solids, however, if used in solutions referred to in 373 gave foams.

391. Among the solids tried, pulverized boiler scale and limestone were the most effective foam producers. In the case of the boiler scale, the only solid tried in this experiment, it was found that the foam-producing tendencies increased, equal weights of material being used, as the size of the particles decreased.

392. In the case of the sodium salts, which were studied in some detail, a fair amount of foam was obtained with concentrations of 1000 p. p. m. if the amount of insoluble material was sufficient. Foaming increased with increasing concentration of the soluble material till about 7000 p. p. m. was reached. After that there was no change.

Increasing the amount of insoluble material had the same effect as an increase in the concentration of the soluble salts. The one could therefore take the place of the other so that foams could be produced with a small amount of soluble material provided a large amount of insoluble solid was present, and vice versa. There was, however, a lower limit at about 500 p. p. m. for both soluble and insoluble material, that is, if the soluble salts were much less than this no reasonable amount of insoluble material would produce foam, and if less than this amount of insoluble matter was present no concentration of soluble salts was sufficient to make the liquid foam.

393. Experiments were made at pressures from about 0.3 to 3.6 atmospheres. No effect was observed except that at the higher pressures the foam bubbles were smaller and more nearly uniform in size and the boiling seemed to proceed more smoothly.

394. Solutions of substances like alcohol that lower the surface tension of water were tried and it was found that with a stabilizing agent, like finely divided solid matter, these solutions also gave foams.

395. By blowing air through a porous alundum crucible foams

⁹³Ind. and Eng. Chem. 14, 601 (1922.)

^{93a}These experiments are contrary to the statement of Koyl (C. H. Koyl, R. R. Gaz. 32, 663 [1900]). Correspondence, however, brought out the fact that the word "foaming" was used by him in a different sense than that employed here so that there is really no conflict.

could be produced at room temperature, and it is worth recording that exactly the same relations held with these air-filled bubbles as with the steam-filled ones of the boiling solutions. Mixtures which foamed on boiling also foamed by blowing air into them at room temperature, and mixtures which did not foam on boiling also did not foam with air.

396. An effort was made to produce a solution that bore some resemblance to a boiler water containing "organic matter." To this end leaves and twigs were boiled with water and the solution filtered. Only two such solutions were made, the results being inconclusive; there was not much tendency to foam.

Prevention of Foaming

397. So far as the author has read, castor oil seems to be the only substance used as a foam preventive in steam boilers. Hobbs^{93b} makes this statement and adds that the action is due to the ability of the oil to raise the surface tension of the water. An experiment with a Du Nouy apparatus showed, however, that water saturated with castor oil has a surface tension about 10% less than that of pure water. The flask experiments on foam prevention are summarized in 398.

398. A mere trace of castor oil stopped almost instantly the foaming of all of the mixtures of soluble material, the films of which had been stabilized with finely divided solids, regardless of whether the dissolved substance raised or lowered the surface tension of the liquid. This effect was so strong that if one drop of the oil was shaken with 100 cc. of water, a few drops of the water was sufficient to stop the foaming of 500 cc. of mixture.

399. These flask experiments confirmed in every particular the theory of foaming as advanced above. The custom of associating foaming with a high concentration of sodium salts is justified because a high concentration of almost any soluble material creates the fundamental condition for the existence of films, and since film-stabilizing material in the form of sludge and loosened scale is nearly always present in a boiler, foaming will occur if the concentration of the sodium salts becomes high.

400. The contradictory statements found in boiler water papers concerning the relation of sodium salts to foaming can easily be harmonized in the light of the theory advanced. Heretofore the two conditions for foam formation, (1) film production and (2) film stabilization, have not been looked upon as separable in boiler water chemistry. Now, by considering that the sodium, or other soluble salts, make possible the formation of films, but that these films because they lack viscosity to give them strength are capable of a momentary existence only, it is seen that such salts alone cannot cause a troublesome foam

^{93b}Railway Age 71, 1132 (1921).

because the bubbles will not last long enough to fill the steam space above the water. If, however, a stabilizing agent, such as finely divided solid matter, is also present, a persistent foam will result. Since in boiler practice any one of the three conditions, sodium salts without solid matter, solid matter without sodium salts, or both sodium salts and solid matter together may occur, it is easy to see how confusion has arisen in tracing the relations of cause and effect without the guidance of a general theory.

401. For the prevention of foaming of the sort caused by mixtures of dissolved substances and finely divided solid matter, castor oil is preeminent. No general theory of foam prevention can as yet be advanced.

CHAPTER XI

PURIFICATION OF WATER FOR INDUSTRIAL USE

402. The purification of water for industrial purposes consists in removing or destroying those constituents that would be injurious for a given use of the water. In other words, the use to which the water is to be put determines the nature of the purification. Sometimes merely a clear water is desired in which case the suspended matter only needs to be removed. In other cases, as for use in steam boilers, scale-forming and corrosive constituents give trouble, and in that commonest and most important industrial application of water, cleaning, the dissolved mineral matter that acts on soap should be removed. It happens that those impurities that destroy soap, or make the water hard, are also the ones that cause scale in steam boilers, and therefore the removal of them is the most important kind of purification. These impurities are the dissolved lime and magnesium compounds, and the elimination of them from water is called softening. The removal of lime and magnesium compounds from a water can be accomplished by precipitating them with chemicals or, to a partial extent, by heating the water (496), or even exposing it a long while to the air. The chemical methods are the most effective and will be described first.

Lime-Soda Method of Softening

General Reactions

403. All of the carbonate or temporary hardness constituents and that part of the permanent hardness due to magnesium compounds can be precipitated from a water by means of lime (calcium oxide). The remaining hardness can then be thrown out by means of soda ash (calcined sodium carbonate). Chemically it makes no difference whether the calculated amounts of lime and soda ash be mixed before their addition to the water or whether they be put in separately (427). The fundamental chemical transformations can, however, be much more clearly presented if it is assumed that the lime is added first and the soda ash later. On this assumption the successive steps are as follows:

404. The lime reacts with some of the water to form calcium hydroxide according to the reaction $\text{CaO} + \text{H}_2\text{O} = \text{Ca}(\text{OH})_2$ and the calcium hydroxide so formed then reacts with any free carbonic acid in the water to form calcium carbonate which precipitates, the reaction being $\text{H}_2\text{CO}_3 + \text{Ca}(\text{OH})_2 = \text{CaCO}_3 + \text{H}_2\text{O}$.

405. Many authors appear to ignore this effect of free carbonic acid in the water. According to the reaction such free carbon dioxide consumes its equivalent of lime, and therefore if left out of consideration in calculating the amount of lime to employ in softening a given water, the result will be low, in other words too little lime will be used. In practice, however, the amount of lime calculated without including the free carbon dioxide seems to be sufficient, at least with those waters which do not have a large amount of such uncombined carbonic acid. The cause of this apparent departure from the path indicated by the chemical reaction may be a two-fold one. In the first place, free carbon dioxide escapes rapidly and it would be the exception rather than the rule that much would be left in the course of handling a water preparatory to treatment. Secondly, according to Pfeifer,⁹⁴ magnesium carbonate is more soluble in the presence of the bicarbonate. The existence of bicarbonate is of course dependent upon a certain concentration of free carbonic acid in the water, and as a consequence, if the latter is partially removed, as by the addition of lime, the concentration of bicarbonate will be reduced, which in turn will cause the precipitation of some basic carbonate. In this way lime will bring about the precipitation of more than its equivalent of magnesium salts and hence less than that equivalent need be added. This effect is evidently about the same as the lime destroying effect of a small amount of free carbon dioxide; hence omitting the latter from the calculation has no great effect on the results. Of course in those methods of determining the lime requirement by experiment (466) any effect of free carbonic acid would be included.

406. After removal of the free carbonic acid the added lime may be assumed to attack next the bicarbonates of calcium and magnesium in the water in the order named.⁹⁵ In all probability the mechanism of the reaction is as follows: By the removal of the free carbonic acid the equilibrium existing between it and the bicarbonate is disturbed, with the result that some of the bicarbonate decomposes into normal carbonate and carbonic acid according to the equation $\text{Ca}(\text{HCO}_3)_2 = \text{CaCO}_3 + \text{H}_2\text{O}$. The calcium hydroxide at once reacts with this free carbonic acid thus causing a continuation of the decomposition of bicarbonate and consequently the precipitation as calcium carbonate of the calcium so combined. The added lime which combined with the carbonic acid also precipitates as carbonate. As a rule the equation is written as if the reaction took place directly between the bicarbonate and the added calcium hydroxide, as follows: $\text{Ca}(\text{HCO}_3)_2 + \text{Ca}(\text{OH})_2 = 2\text{CaCO}_3 + 2\text{H}_2\text{O}$. The analogous reaction with magnesium bicarbonate runs, $\text{Mg}(\text{HCO}_3)_2 + \text{Ca}(\text{OH})_2 = \text{MgCO}_3 + \text{CaCO}_3 + 2\text{H}_2\text{O}$.

⁹⁴Kritische Studien über Untersuchung und Reinigung des Kesselspeisewassers, Z. für. Angew. Ch. 15, 193 (1902).

⁹⁵Bartow and Jacobson, University of Illinois Bulletin, Vol. 8, No. 23, Survey of the Waters of Illinois, p. 88.

407. According to the above, it is seen that all bicarbonates, that is, the carbonate or temporary hardness constituents, are decomposed by the addition of lime with the formation of the normal calcium and magnesium carbonates, CaCO_3 and MgCO_3 . Of these, calcium carbonate is insoluble and settles out. The magnesium carbonate, however, is fairly soluble and consequently much of it remains in solution making the water hard to that extent. Advantage is therefore taken of the fact that another compound of magnesium, the hydroxide, $\text{Mg}(\text{OH})_2$, is as little soluble as calcium carbonate, and, as it happens, is precipitable by calcium hydroxide. Enough more lime is therefore added to react with the magnesium carbonate and convert it into hydroxide, the reaction being, $\text{MgCO}_3 + \text{Ca}(\text{OH})_2 = \text{Mg}(\text{OH})_2 + \text{CaCO}_3$. It is seen that the calcium and magnesium change places. Both compounds are insoluble and settle out. These two reactions involving the complete precipitation of the magnesium originally combined as bicarbonate may be written as one and become then, $\text{Mg}(\text{HCO}_3)_2 + 2\text{Ca}(\text{OH})_2 = \text{Mg}(\text{OH})_2 + 2\text{CaCO}_3 + 2\text{H}_2\text{O}$.

408. In the next step of the process advantage is again taken of the fact that calcium hydroxide forms the insoluble magnesium hydroxide and more lime is added to precipitate any magnesium remaining in the water, or, in other words, that part of the noncarbonate or permanent hardness due to magnesium compounds. Since all of the bicarbonates are disposed of by the first additions of lime the remaining magnesium compounds will be sulfates, chlorides, or nitrates. Any of these will react with calcium hydroxide as follows: $\text{MgCl}_2 + \text{Ca}(\text{OH})_2 = \text{Mg}(\text{OH})_2 + \text{CaCl}_2$. According to this equation it is seen that though the magnesium is precipitated, no softening has taken place because a corresponding amount of soluble calcium salt is left in the water. The same would be true of the nitrate and sulfate of magnesium. These calcium salts would be soluble in amounts equivalent to the magnesium likely to remain in a water after the destruction of the bicarbonates. This equivalent calcium must be removed later by means of soda ash. It is economical nevertheless to remove the permanent hardness magnesium with lime because soda ash will not do it effectively on account of the rather high solubility of magnesium carbonate.

409. The last step in the softening process is the removal of the calcium chloride, sulfate, or nitrate originally in the water, and any that may have been produced by the precipitation of the corresponding salts of magnesium as described in 408. This is done by precipitating with soda ash, sodium carbonate, the following reaction being typical: $\text{CaCl}_2 + \text{Na}_2\text{CO}_3 = \text{CaCO}_3 + 2\text{NaCl}$. If the calcium is combined as sulfate or nitrate, sodium sulfate or nitrate will be left in the water.

Waters Containing Alkaline Bicarbonates

410. Waters are occasionally met that contain alkaline bicarbonates in addition to those of calcium and magnesium and those not familiar with water chemistry will be surprised at the amount of calcium and magnesium that such waters sometimes carry. Ohio has few waters of this type but in some parts of the country they are common. The Illinois Water Survey, for example, records a large number of supplies of this character.⁹⁶ Such waters are always characterized by an alkalinity in excess of the total hardness. Since considerable calcium and magnesium salts are often present they need to be softened for some purposes, and when this is tried the calculated amount of lime fails to have the expected softening effect. This, according to Bartow and Lindgren,⁹⁷ is due to the order in which the various reactions between the lime and the mineral constituents of the water take place. They give the possible reactions as follows:

1. $\text{Ca(OH)}_2 + 2\text{CO}_2 = \text{Ca(HCO}_3)_2$
2. $\text{Ca(OH)}_2 + \text{Ca(HCO}_3)_2 = 2\text{CaCO}_3 + 2\text{H}_2\text{O}$
3. $\text{Ca(OH)}_2 + 2\text{NaHCO}_3 = \text{CaCO}_3 + \text{Na}_2\text{CO}_3$
4. $2\text{Ca(OH)}_2 + \text{Mg(HCO}_3)_2 = 2\text{CaCO}_3 + \text{Mg(OH)}_2 + 2\text{H}_2\text{O}$

411. By a series of experiments, consisting of progressively increasing lime additions to a hard water containing an excess of sodium bicarbonate, they show that the reactions take place in the main in the order given above. From this it is seen that on addition of the amount of lime calculated to react with the free carbonic acid, the bicarbonates of calcium and magnesium, and to provide for the precipitation of the magnesium as hydroxide, the calcium bicarbonate will be decomposed and precipitated much the same as if no sodium bicarbonate were present, but that then the remaining lime will react with the sodium bicarbonate instead of with the magnesium compound. According to this such waters are readily freed from their calcium bicarbonate hardness but an undue excess of lime will be required to remove the magnesium.

412. The removal of lime and magnesia from waters containing an excess of sodium bicarbonate appears of relatively little importance if one judges by the scarcity of publications on the subject. Among the various books on water softening which the author has looked over, only one, that of Wehrenfennig, touches upon the subject. Wehrenfennig suggests treatment with lime and magnesium sulfate, lime and ferrous sulfate, lime and calcium sulfate, or lime and sodium acid sulfate, but does not cite any actual experiences with such procedures.

⁹⁶Bartow, Udden, Parr, and Palmer, *The Mineral Content of Illinois Waters*. See Nos. 481, 484, 485, 514, 515, and 523 in this Illinois bulletin.

⁹⁷J. Am. Chem. Soc. 29, 1293.

Extent of Softening by Lime-Soda Method

413. It must not be assumed that all of the calcium and magnesium can be removed from a water by adding the calculated amounts of lime and soda ash according to the above equations. Several things interfere with this. Both the carbonate of calcium and the hydroxide of magnesium are distinctly soluble in pure water, and this solubility is increased by the presence of certain other salts in solution.⁹⁸ The solubility can, however, be reduced by adding an excess of lime and soda ash, the excess of soda ash being so adjusted that it removes the excess of lime and leaves an equivalent amount of sodium hydroxide. Boiler feed waters are often overtreated in this way.

414. Just how much calcium and magnesium will be left in a water on treating it with the calculated amounts of lime and soda ash will of course depend upon the nature and concentration of other substances present, upon the temperature, and upon the time the water stands before using it. Generally a large amount of other salts tends to increase the solubility of the calcium and magnesium precipitates, that is, more will remain in the water after softening treatment; an increase in temperature will have the opposite effect, the softening being greater than at a lower temperature and, during the first few hours, the longer the water stands the greater will be the softening.

Parr⁹⁹ states that the solubility of the mixed calcium carbonate and magnesium hydroxide at ordinary temperatures is from 2 to 5 grains per gallon or, roughly, 51 to 86 parts per million. At 50° F. the scale-forming constituents could be reduced to 1 to 1.5 grains per gallon, or 17 to 26 parts per million. Mr. W. A. Powers of the Santa Fe Railway is cited as the authority for the latter statement.

415. Pfeifer¹⁰⁰ treated solutions of calcium and magnesium salts with varying amounts of softening reagents at room temperature with the following results: (1) The minimum hardness to which a calcium bicarbonate solution could be reduced with lime was 30.6 parts per million CaCO_3 . (2) The minimum hardness to which a magnesium bicarbonate solution could be reduced with lime was 64.4 parts per million equivalent CaCO_3 . This experiment was also tried at 80° but no increased effect was observed. (3) The minimum hardness to which a magnesium chloride solution could be reduced with lime and soda ash was 40.3 parts per million equivalent CaCO_3 in the cold and 30.6 at 80°. (4) The minimum hardness to which a calcium sulfate solution could be reduced with soda ash in the cold was 50.4 parts per million CaCO_3 . At 90 to 95° a further reduction to 30.2 parts was obtained. It is difficult to tell from Pfeifer's tables just how much soda ash was

⁹⁸Stillman and Cox, *J. Am. Chem. Soc.* 25, 732.

⁹⁹The Chemical Examination of Water, Fuel, Flue Gases, and Lubricants, p. 25.

¹⁰⁰*Zeit. für angewandte Ch.* 1902, 202.

employed but apparently it was about the equivalent of the calcium sulfate.

416. Whipple and Mayer¹⁰¹ discuss the solubility of calcium carbonate and magnesium hydroxide in pure water and call attention to the fact that previous determinations of the solubility of calcium carbonate fall into two groups. In one group the results are in the neighborhood of 34 parts per million while in the other an average of about 13 parts per million is found. The probable cause of the discrepancy is the failure on the part of those who obtained the higher values to guard against the action of carbon dioxide from the air and the action of the calcium carbonate solutions on glass. Whipple and Mayer also made a series of careful determinations of the solubilities and state that the most probable value for the solubility of calcium carbonate in pure water is 13 parts per million and that for magnesium hydroxide is 10 parts.

417. Gothe¹⁰² found the solubility of calcium carbonate in pure water free from carbonic acid to be 31 parts per million. The solubility of magnesium carbonate under the same conditions could not be determined accurately, but the value 94 parts per million is given as an approximation. The most interesting part of Gothe's investigation, however, is the effect of other salts on the solubility of these carbonates. He found for example that 2.34 grams of sodium chloride per liter increased the solubility of calcium carbonate over 15% and that of magnesium carbonate over 36%. The effect of sodium nitrate and sulfate was even greater. Gothe also experimented with organic matter using a peaty water. A large addition of such water increased the solubility of calcium carbonate nearly 90% and that of magnesium carbonate about 70%. It was also found in this investigation that the presence of salts of the alkaline earths neutralized the solvent action of salts of the alkalis and of organic matter. Gothe used concentrations of salts and of organic matter considerably larger than occur in Ohio waters, but then it must be noted that the effects were also large. In the amounts ordinarily present in hard waters the effects would be apparent and would serve in large measure to explain occasional failures to get expected results.

418. This solvent action upon calcium and magnesium carbonates, and presumably also upon magnesium hydroxide, of alkali salts and organic matter has as yet no adequate theoretical explanation. As to the organic matter, it has been suggested that it behaves as a protective colloid.¹⁰³ The phenomenon of after deposits (426) from softened water would seem to indicate that some of the calcium carbonate is in the colloidal state.

¹⁰¹Jr. Infect. Diseases, Supplement 2, 151.

¹⁰²Chem. Zeitung. 39, 305.

¹⁰³Noll, Jour. für Gasbeleuchtung 941, 1914.

419. Parr's figures above are general and those of Pfeifer and Gothe deal with pure solutions. The practical question is the degree of softening to be attained with a given, actual boiler water. There is no theoretical answer to this even when a very complete analysis of the water is at hand. The chemist having the situation in charge should vary the additions of lime and soda ash on both sides of the calculated values until the optimum result is obtained. This optimum result will be determined by the use of the softened water. In some cases the desirability of reducing the calcium salts with an excess of soda ash is greater than the disadvantage of the resulting alkalinity and the added cost. In other cases, even the minimum softening reached by the calculated additions is not needed. All of these points must be considered. Naturally occurring waters often present individual peculiarities¹⁰⁴ and experiment alone will give the best treatment. It must be remembered though that the lime and soda ash treatment will not give a water of zero hardness.

420. Under the best conditions calcium and magnesium amounting to about 50 parts per million, or 3 grains per gallon, of total hardness will be left in the water if the softening is done cold. A hot process may reduce the figures to half the above values. As a general rule a softer water is obtained with an intermittent than with a continuous softener because the control is closer. It is interesting, however, to suggest another cause^{104a} for the better results of the intermittent softener. As a rule the operator puts a little water into the tank and the lime and soda ash mixture to soften the tankful. The pumping is then continued till the tank is full, with the result that all the water but the last portions has the benefit of excess treatment. (See 424.)

Effect of Temperature Changes on Lime-Soda Reactions

421. From the figures of Parr and Pfeifer above it is seen that the efficiency of the softening process is increased by increasing the temperature. The gain is a three-fold one. Not only is a softer water obtained but a given degree of softening is reached in less time and the precipitated sludge settles out faster.

422. There has been little quantitative study of the temperature coefficients of these reactions but it is perhaps safe to say that at or near the boiling point of water as much softening is accomplished in a minute as in an hour at the average out-door temperature. Read¹⁰⁵ gives charts which show as much precipitation in five minutes at 200 to 210° F. as in five hours at 50° F. Experiments¹⁰⁶ in the author's

¹⁰⁴J. C. W. Greth, *J. Ind. and Eng. Chem.* 3, 13.

^{104a}Private communication from C. P. Hoover.

¹⁰⁵*Boiler Waters, Their Chemical Composition, Use, and Treatment*, University of Texas Bulletin No. 1752, page 64.

¹⁰⁶From an unpublished senior thesis by B. H. Mohler.

laboratory showed a marked difference as between the out-door temperatures of summer and winter. Chemists having control of softening plants find in this temperature effect an explanation of some of their troubles.

423. Industrial advantage is taken of the increased rate and efficiency of the softening reactions at higher temperatures by treating the water with lime and soda ash near its boiling point. The gain of such treatment lies in the fact that a much smaller equipment is necessary than for the cold process because, owing to the rapid rate of softening, the various tanks can be used oftener in a day. Hot softeners are of special value in steam plants because the water must in any event be heated and there is, therefore, no loss of energy. Combined preheaters and softeners are on the market.

424. The question, how long does it take to soften a given amount of water at average out-door temperature, is a practical one, but difficult to answer because of the variable composition of natural waters and the variations that may exist in the method of treatment. For example, it has been found that the mixing of old sludge through the treated water results in more rapid settling and possibly also in more rapid precipitation. The particles of old sludge seem to act as nuclei for the formation of the new precipitate. It has also been found of great value to overtreating the larger portion of the water and then add later the untreated part. The large excess of reagents used in the larger portion causes a prompt settling, so that even if the smaller portion added later was not benefited there would still be a distinct net advantage. Sometimes, however, a good "floc" is not obtained, that is, the precipitate is slimy and settles slowly. The amount of agitation after adding the lime and soda ash is also a factor in the sense that increased agitation increases the rate of the reactions somewhat and improves the physical condition of the sludge. Obviously, however, agitation dare not encroach too much upon the time for settling. It is the practice in some places to add the calculated amount of lime first and some minutes later follow with the soda ash. In other places the two reagents are mixed outside the treating tank and the mixture added to the water. These two practices with certain waters at least would produce different results. Instances like the above of variations in softening conditions might be indefinitely extended, but all can be generalized under one statement; every variation of treatment can be expected to have an effect on the softening, chiefly on the physical character of the sludge. The nature of the effect, whether the sludge will settle more slowly or more rapidly, may vary with different waters. If trouble arises, try one change after another and note the effect. Perhaps it is a safe statement to make that three hours is the minimum time of settling to obtain a water clear enough to run into a boiler. If from six to twelve hours can be employed better results will be obtained.

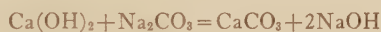
After Precipitations

425. Even under the best of management a small amount of precipitate, chiefly calcium carbonate, remains in the softened water and will in time precipitate. In large municipal plants where softening is followed by rapid sand filtration, this after precipitation takes place on the grains of sand to such an extent that in the course of six or seven years the beds consist of more than 75 per cent calcium carbonate.¹⁰⁷

426. It seems reasonable to suppose that these after deposits result from the gradual crystallization of colloidal calcium carbonate in the water. When such a water is conducted through a considerable length of piping the deposit will take place in the pipes. In a boiler the deposit appears as scale or sludge. All told, these after deposits are a great nuisance and various schemes have been tried to eliminate them, the commonest being conversion to acid carbonate by treating the water with carbon dioxide made by burning coke.¹⁰⁸

Order of Adding Lime and Soda Ash

427. In most water softening practice the calculated amounts of lime and soda ash are mixed before they are added to the water. They react with each other according to the equation,



The mixture will contain Ca(OH)_2 or Na_2CO_3 in addition to the CaCO_3 and NaOH , depending upon which was in excess as calculated by the reaction. It is somewhat puzzling at first to see how such a mixture works chemically the same as if the constituents were added separately. The calcium carbonate is inert and the sodium hydroxide formed has no carbonate ion in it. A typical case will make the matter clear. Let the amounts of lime and soda ash calculated from a given water be such that the lime is in excess of the soda, then on mixing these amounts the mixture will consist of calcium carbonate, caustic soda equivalent to the soda ash, and the excess of calcium hydroxide. The caustic soda and calcium hydroxide together will be equivalent to the calculated amount of lime, and the caustic soda will be the equivalent of the calculated amount of soda ash. On adding this mixture to a water, the

¹⁰⁷Growth of filter sand at three water softening plants. Part I. Nine years experience in Columbus, Ohio, by C. P. Hoover, Eng. News-Record 78, 250. Part II. Five years experience at Grand Rapids, Mich., by W. A. Sperry, Ibid., 78, 304. Part III. Eight years experience at McKeesport, Pa., by E. C. Trax, Ibid. 78, 351.

¹⁰⁸Campion, H. T., A Study of the Behavior of the Carbonation of the Defiance Water Softening Plant. Third Annual Report of the Ohio Conference on Water Purification, page 39 (1924). Also C. P. Hoover, Proposed Carbonation Method for Columbus Water, page 62. Also N. S. Hill, Jr., Recarbonization of Softened Water, Jour. Am. Water Works Assoc. 11, 393 (1924).

calcium hydroxide will function as usual and the caustic soda will react according to the following equation:



It is seen from this that the lime and caustic soda together precipitate the bicarbonates the same as if the originally calculated amount of lime had been used separately, and that an amount of sodium carbonate is produced exactly equivalent to the original amount of soda ash as calculated. The reader may be left to carry out a similar line of reasoning concerning the case in which the calculated amount of soda ash is greater than the lime.

428. Chemically then it makes no difference whether the lime and soda ash are added to the water separately or mixed, neither does it matter in what order they are added if they are put in separately. Different effects may, however, appear in the physical condition of the precipitates. A dense crystalline precipitate is always desired because it is more insoluble than a light, slimy one, and because it settles more rapidly and is easier to filter. The general question of the physical condition of the precipitates obtained in water softening is probably one of colloid chemistry and has as yet not been thoroughly investigated. The character of the water undoubtedly plays an important role and, therefore, a procedure that produces good results with one water may not do so with another one.

Incidental Purification by Lime-Soda Method

429. Iron, and to a lesser extent manganese, will be removed by the lime-soda process. Suspended, clayey matter will be entangled in the amorphous precipitates and will be carried down by the sludge, thus giving a clear water. Color will be lessened and bacteria will be reduced in numbers to the extent of 75 to 85 per cent, the action being the same as in the removal of clayey matter.

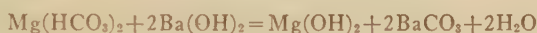
Miscellaneous Reagents for Softening

430. Fifteen to twenty reagents other than lime, soda, and zeolites might be mentioned that have been suggested for the softening of water but grounds of cheapness and efficiency have prevented their use excepting for special purposes. Among such reagents are borax (household use), sodium fluoride, sodium phosphate, sodium hydroxide, barium carbonate, and barium hydroxide. Of these sodium hydroxide has been used to some extent but cannot compete with lime. Barium carbonate and hydroxide have the important property of precipitating sulfates and therefore deserve special mention for the softening of those

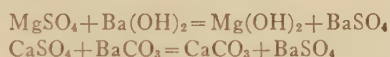
waters in which the lime-soda and the zeolite methods would leave a too high concentration of sodium salts. It must be said, though, that at the present price of barium compounds their use is prohibitive excepting under special conditions.¹⁰⁹ The interesting chemical possibilities suggest their discussion here.

Use of Barium Compounds

431. Barium oxide like lime immediately reacts with water to form the hydroxide, $\text{Ba}(\text{OH})_2$, which, however, is more soluble than the corresponding calcium compound and therefore more effective as a precipitant. Its reactions with bicarbonates are like those of lime as shown by the following typical case:



It will be noted that not only are the bicarbonates decomposed and magnesium precipitated but that the barium also comes down. The same ideal condition holds for the precipitation of that part of the permanent hardness due to calcium and magnesium sulfates.



All of the products of these reactions are insoluble. In so far as the non-carbonate hardness consists of chlorides and nitrates there is no advantage over soda ash since the corresponding salts of barium are also soluble.

432. Reference to the reactions above show that many interesting combinations may develop depending upon the relative amounts of carbonate and sulfate hardness. For example, the barium carbonate resulting from the decomposition of the bicarbonates of calcium and magnesium can react with calcium sulfate to form the two insoluble substances, calcium carbonate and barium sulfate. Since barium compounds are relatively expensive their use may be combined with lime. Snouk and Bartow¹¹⁰ have experimented with such a combination. Barium carbonate used alone for the removal of sulfates and calcium from a water has a particular advantage in that it is so insoluble that an excess can be added at once. It will react only as needed till all is exhausted. Little or no experience in the use of barium compounds on a large scale seems to be recorded and that on a laboratory scale is also scarce. It is a promising field for research.

¹⁰⁹Mr. C. F. Long, a consulting chemist of Columbus, Ohio, informs the author that he uses barium in softening one of the locomotive feed waters for the T. & O. C. R. R. in order to avoid the serious foaming caused by the large amount of sodium salts that would be introduced by the straight lime-soda process.

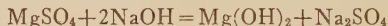
¹¹⁰Illinois State Water Survey No. 13, 303.

Use of Sodium Hydroxide

433. Sodium hydroxide deserves special mention as a softening reagent because it is a constituent of many boiler compounds and its use is often suggested in small scale operations. It should, however, receive careful chemical consideration. It reacts with the bicarbonates and with magnesium just as calcium hydroxide does (406, 407, 408) but with this difference, the sodium carbonate which forms is soluble and will, therefore, react with the calcium that is equivalent to the non-carbonate hardness. The reaction with the bicarbonate of calcium is as follows:



434. The reaction with magnesium bicarbonate is similar so that it is seen that an equivalent of sodium carbonate will be formed for each equivalent of carbonate hardness, and, in addition, another equivalent for each one of magnesium carbonate decomposed and precipitated as magnesium hydroxide. In the precipitation of the magnesium, originally in the form of chloride or sulfate (the non-carbonate hardness magnesium), no sodium carbonate is formed as the following typical reaction shows:



435. A consideration of the above situations shows that if the non-carbonate hardness of a water happens to be equivalent to the carbonate hardness plus the magnesium bicarbonate, caustic soda will be a complete softening reagent because the sodium carbonate formed in softening the one group of hardness constituents will be just the right amount for precipitating the other group. Such a relation is, however, very unlikely. One group or the other will be in excess. If the total bicarbonates plus the magnesium bicarbonate is greater than the non-carbonate hardness, there will be an excess of sodium carbonate in the water if sufficient hydroxide had been used to precipitate the carbonate hardness. With such a water only enough sodium hydroxide should be used to furnish sodium carbonate equivalent to the non-carbonate hardness. This will of course not be enough hydroxide for the carbonate hardness and the deficiency should be supplied by adding lime. Conversely, if the non-carbonate hardness is in excess there will not be enough sodium carbonate formed by the reaction of the hydroxide with the carbonate hardness and therefore some soda ash will have to be added.

Equipment for Softening by the Lime-Soda Process

436. The lime-soda process is carried out by one of two general

plans, intermittent or continuous. In the intermittent process a tank of water is treated with the calculated amount of reagents, stirred, and after a proper period of subsidence the clear, soft water is drawn off. The continuous system is so planned that the chemicals are automatically introduced into a current of the hard water which then follows a tortuous course around baffles to give time for the sludge to settle so that the treated water emerges clear in a steady stream at the outlet.

Intermittent Softeners

437. The mechanical equipment of an intermittent softener consists of a tank provided with a stirring device, an inlet for raw water, and a floating outlet for the soft water so that it may be drawn from the surface and thus secure the maximum subsidence time for the bulk of the supply. Provision for running off the sludge must also be made. In addition there is a small mixing tank for preparing the chemicals. This must be provided with a stirrer and, if located on the floor, with a pump for transferring the chemicals to the tank. In some installations the chemical mixing tank is above the treating tank thus permitting the lime and soda ash to flow in by gravity.

438. The operating procedure consists in testing the tankful of raw water, and on the basis of this test calculating and adding the dose of lime and soda. The stirring device of the treating tank is kept operating for about an hour to provide thorough mixing of the chemicals and old sludge with the water and thus hasten the reactions. After this reaction period the water is allowed to rest for from four to six hours to provide for settling of the sludge. For many purposes this settled water is sufficient; in some installations, however, it is filtered. The above description is for one unit only which can be built in a variety of sizes. Large installations consist of several treating tanks which can be supplied by one chemical mixing tank. In this way one tankful of water can be treated while another is subsiding. By adding more treating tanks the installation can be enlarged almost indefinitely.

439. The advantages of the intermittent system lie in the accurate regulation of the chemicals to the water, a point of importance in treating surface waters which usually vary in composition over wide limits; in the ease with which errors in treatment can be adjusted; in the simplicity of the apparatus employed, thus calling for the minimum of attention to the mechanical parts; and in the ease with which the plant can be enlarged as more demands are made upon it. Its chief disadvantages are the larger space demanded as compared with a continuous system of the same capacity and a greater first cost of installation.

Continuous Softeners

440. Excepting the large installations for softening a city supply, the continuous softener is a vertical tank consisting of two essential parts: (1) an inner mixing chamber of small diameter, usually provided with an agitator, at the top of which the raw water and chemicals are introduced in a continuous stream, and (2) an outer part of large diameter through which the treated water rises slowly to provide time for the sludge to settle. In this way a continuous stream of clear, soft water is furnished, which may be used as it leaves the softener or be filtered according to its proposed use. An essential part of the equipment is a small chamber for mixing the chemicals and an automatic mechanical device for adding them in proper adjustment to the rate of inflow of the hard water. The interior of the vertical tank is further frequently provided with an intricate set of baffles to facilitate the mixing and to provide places of deposit for the sludge. A not infrequent addition at the top of the soft water compartment is a filtering layer of sand or excelsior which removes the last traces of suspended matter. There are of course appropriate valves for regulating the flow of water through the apparatus and for disposing of the sludge.

441. The operation of a continuous softener is, theoretically at least, simplicity itself. The chemist furnishes the formula for the lime and soda ash. These are put into the mixing chamber and the water turned on. After that everything is automatic. If the rate of flow of raw water varies the addition of the lime-soda mixtures automatically varies in the same way. Sludge is drawn off from time to time and the supply of chemicals must be kept up.

442. The advantages of the continuous system lie in the smaller space occupied, the smaller first cost of installation, and in the lesser attention demanded on account of the automatic regulatory devices. Its disadvantages are the greater difficulty of adjusting the chemicals to rapid changes in the composition of the raw water and in the mechanical difficulties peculiar to automatic devices.

Choice of a Softener System

443. Obviously the choice of a system is a matter that can be determined only by conditions. Economy of space and cost of installation must be balanced against refined control of the quality of water furnished and the ease with which the capacity of the plant can be increased. Water softeners like engines and boilers are made to sell. Each manufacturer of softeners has his pet appliances and patented feeding and measuring devices. Not all of them are good. The average Ohio manufacturer using the average Ohio hard water in his boilers will always find that softening pays, but the best softener can be determined

only by knowing all about the conditions of the factory, the raw water, and the use to which the soft water is to be put. It is a question that can be decided only by a competent chemist or chemical engineer.

Chemical Investigation of Raw Water

444. In order to calculate the amounts of lime and soda ash for softening a given water, the amounts of the following constituents must be known:

Free carbonic acid
Carbonate hardness
Non-carbonate hardness
Total magnesium

In addition it is desirable to know the amount of sodium chloride, sulfate, and nitrate ions and total organic matter,¹¹¹ because these substances influence the lime-soda reactions, and knowledge of the amounts present will aid the chemist in understanding the behavior of the water during softening. The following detailed procedure is recommended:

445. On receipt of the sample its turbidity and color should be noted. If there is much finely divided solid matter in the water it may be necessary to use a coagulant (513) in order to obtain a clear water after softening. If the water is colored yellow or brown dissolved vegetable matter is indicated, which might interfere with the softening reactions (417).

446. The sequence of chemical work should be as follows: (1) Determine the free carbonic acid. (2) Start the determination of total solids and eventually ignite the residue at a red heat to get what information this may afford as to the presence of organic matter. A blackening with the odor of charring wood indicates vegetable matter and an odor of burning flesh points to animal matter. Sometimes little sparks will be seen during the ignition. This probably is caused by the simultaneous presence of organic matter and nitrates. The residue after ignition may be weighed but the information gained will be of little value.

447. (3) Determine the carbonate or temporary hardness, that is, determine the alkalinity with methyl orange or erythrosine. At this point it will be well also to note the reaction of the water to phenolphthalein. If a red color is produced it indicates the presence of normal carbonates or of hydroxides, or both, and it may then be necessary to titrate another portion of the water using phenolphthalein as indicator and calculate the amounts of the different forms of alkalinity. Some natural waters show phenolphthalein alkalinity and treated waters

¹¹¹The determination of the so-called oxygen consumed as made in the routine sanitary analysis of a water will serve as a measure of total organic matter. In the present state of our knowledge of the effect of organic matter on the softening reactions a quantitative determination has little value however.

very commonly do so. Surface waters polluted with trade wastes may of course show any reaction.

448. A water originally high in carbonate hardness, and which has been exposed to the air for some time, or which has been heated, will give a red color with phenolphthalein due to the slight amount of calcium carbonate in solution. The absence of hydroxides can quickly be determined by adding a drop or two of barium chloride solution. The barium reacts at once with the carbonate ion to form the insoluble barium carbonate and the red color will immediately be discharged.

449. An occasional hard water will be encountered that is acid even to methyl orange. This would be true of certain waters and occasionally of streams polluted with trade wastes. Such a water would have no carbonate or temporary hardness and before treating it the acid would have to be neutralized. To calculate the amount of such neutralization it would be necessary to determine the acidity of the water which can be done by titrating a measured portion with standard alkali (0.05N).

450. (4) Determine the non-carbonate hardness. It of course makes no difference how the non-carbonate hardness is found. It may be done directly by the soda reagent method or the total hardness may be determined by soda reagent, or by determining the total calcium and magnesium and then get the non-carbonate hardness by subtracting the carbonate value from the total.

451. Waters will often be found in which the carbonate hardness as determined by titrating with methyl orange is greater than the total hardness. This paradoxical situation is due to the presence of sodium carbonate, bicarbonate, or hydroxide. A surprisingly large amount of calcium and magnesium salts may accompany a considerable amount of sodium bicarbonate, and in case such a water is to be softened an undue amount of lime (410) will be required.

(5) Determine the total magnesium.

Lime and Soda Ash Requirements

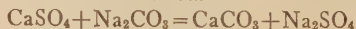
General Discussion

452. To make reference easier the fundamental reactions of the lime-soda process are reproduced here.

I. Reactions with lime.

- (1) $\text{H}_2\text{CO}_3 + \text{Ca}(\text{OH})_2 = \text{CaCO}_3 + 2\text{H}_2\text{O}$
- (2) $\text{Ca}(\text{HCO}_3)_2 + \text{Ca}(\text{OH})_2 = 2\text{CaCO}_3 + 2\text{H}_2\text{O}$
- (3) $\text{Mg}(\text{HCO}_3)_2 + \text{Ca}(\text{OH})_2 = \text{MgCO}_3 + \text{CaCO}_3 + 2\text{H}_2\text{O}$
- (3a) $\text{MgCO}_3 + \text{Ca}(\text{OH})_2 = \text{Mg}(\text{OH})_2 + \text{CaCO}_3$
- (4) $\text{MgSO}_4 + \text{Ca}(\text{OH})_2 = \text{Mg}(\text{OH})_2 + \text{CaSO}_4$

II. Reaction with soda ash.



In these reactions the sulfates of magnesium and calcium are used merely as typical of the non-carbonate hardness. The chlorides and nitrates might also be present and would react in the same way.

453. An inspection shows that the total lime needed for softening a water is as follows: One equivalent of lime for each equivalent of free carbonic acid, reaction (1); one equivalent of lime for each equivalent of calcium bicarbonate, reaction (2); one equivalent of lime for each equivalent of magnesium bicarbonate, reaction (3); one equivalent of lime for each equivalent of magnesium carbonate formed in reaction (3), reaction (3a); and finally, one equivalent of lime for each equivalent of magnesium combined as sulfate, chloride, or nitrate.

454. These lime requirements are plain and definite but they do not coincide with the data of the ordinary water analysis which measures the total amount of bicarbonates, that is, the carbonate hardness, without distinguishing the calcium and magnesium bicarbonates separately. Similarly the total non-carbonate hardness is determined without attempting to divide it into two parts, one caused by calcium sulfate, chloride, or nitrate, and the other by the corresponding magnesium salts; or if the total magnesium and total calcium are determined, there is no way of distinguishing which part is present as bicarbonate and which is there as sulfate, etc. In view of these considerations, therefore, it becomes necessary to translate the lime requirements as shown by the reactions above into the terms of water analysis. Fortunately it is a simple matter, and when so transformed becomes the following:

(1) One equivalent of lime for each equivalent of carbonic acid.

(2) One equivalent of lime for each equivalent of carbonate hardness.

(3) One equivalent of lime for each equivalent of the total magnesium irrespective of its form of combination.

455. The reaction with free carbonic acid remains the same as given in 452 and needs no explanation. The carbonate hardness corresponds to reactions (2) and (3), and owing to the fact that the magnesium carbonate resulting from reaction (3) requires an extra equivalent of lime to transform it into the insoluble hydroxide, it is seen that reactions (3a) and (4) correspond to the total magnesium. Thus it is seen that free carbonic acid, carbonate hardness, and total magnesium are chemically equivalent to the fundamental reactions which give the lime requirements.

456. Soda ash is required to precipitate the salts equivalent to the non-carbonate hardness, which it will be recalled is due to those compounds of calcium and magnesium other than the bicarbonates. It is at first puzzling to see that the total non-carbonate hardness must have its equivalent of soda ash in spite of the fact that the magnesium combined as sulfate is precipitated with lime. The puzzle is solved,

however, as soon as one notes that in reaction (4) above an amount of calcium sulfate exactly equivalent to the original magnesium compound remains in solution in the water. In other words the precipitation of magnesium sulfate with lime leaves the water as hard as before.

457. In softening operations on a large scale the formulas for adding reagents are usually given in terms of pounds avoirdupois per 1,000 gallons of water, and industrial water analyses are usually stated in terms of grains per U. S. gallon. The required lime and soda ash are also sometimes given as grains per gallon. In recent years, however, there is a growing tendency to report analyses in parts per million, and it is, therefore, necessary at times to calculate the values of one system in terms of the other. This can be done according to the following formulas:

$$\text{Parts per million} \times 0.05842 = \text{grains per U. S. gallon.}$$

$$\text{Grains per U. S. gallon} \times 17.12 = \text{parts per million.}$$

$$\frac{\text{Grains per U. S. gallon}}{7} = \text{pounds avoirdupois per 1,000 gallons.}$$

$$\text{Parts per million} \times 0.0083 = \text{pounds avoirdupois per 1,000 gallons.}$$

458. According to the fundamental reactions as given above the active lime softening reagent is calcium hydroxide, Ca(OH)_2 . It is possible to buy calcium hydroxide (hydrated lime) on the market, but in the operation of a large softener burnt lime, CaO , is almost universally used, and the calculations below are made accordingly. Since the molecular weight of calcium oxide, CaO , is 56, and that of calcium hydroxide, Ca(OH)_2 , is 74, their relative values as softening reagents are 56 lbs. of $\text{CaO} = 74$ lbs. of Ca(OH)_2 or 1 lb. of burnt lime is as effective as 1.321 lbs. hydrated lime.

Calculation of Required Lime

459. (1) Lime required to react with the free carbonic acid. Free carbonic acid is usually stated, as in the analyses of this Bulletin, in terms of carbon dioxide, CO_2 , one equivalent of which is equal to one equivalent of carbonic acid, H_2CO_3 . Since the chemical relation of CaO and Ca(OH)_2 is as one to one, it follows according to the reaction that for each equivalent of free carbon dioxide in a water there must be added one equivalent of lime, CaO . The further details of the calculation are as follows:

$$56.07 (\text{CaO})^{112} : 44 (\text{CO}_2) :: \text{wt. of CaO required} : \text{wt. of CO}_2$$

The expression $\frac{56.07}{44}$ gives the relation by weight existing be-

¹¹²In this and in the following equations the molecular weights with the chemical formulas of the substances in question are used.

tween any amount of free carbon dioxide and the lime required to react with it in the softening process. When reduced to a decimal fraction it becomes 1.2743, and the following simplified expression can therefore be written:

$$\left\{ \begin{array}{l} \text{Lime required for the free CO}_2 \\ \text{in a given volume of water} \end{array} \right\} = \left\{ \begin{array}{l} \text{Weight of free CO}_2 \\ \text{in same volume} \end{array} \right\} \times 1.2743$$

For example, one grain per gallon free carbon dioxide will require 1.2743 grain per gallon lime, and one part per million free carbon dioxide will take 1.2743 part per million, that is, 1.2743 milligram per liter of lime, etc.

The number of pounds of lime^{112a} to react with the carbon dioxide in 1,000 gallons of water is given by the following expressions:

$$(A) \frac{\text{Grains per gallon CO}_2 \times 1.2743}{7}$$

$$(B) \frac{\text{Parts per million CO}_2 \times 0.05842 \times 1.2743}{7}$$

When these formulas are simplified, they become,

$$(A_1) \text{ Grains per gal., CO}_2 \times 0.1820 = \text{pounds lime per 1,000 gallons.}$$

$$(B_1) \text{ Parts per mill., CO}_2 \times 0.0106 = \text{pounds lime per 1,000 gallons.}$$

460. (2) Lime required to react with the carbonate hardness or alkalinity. The bicarbonates in a water constituting the carbonate hardness are given in terms of calcium carbonate, an equivalent of which is equal to an equivalent of calcium or magnesium bicarbonate, therefore the lime requirement is shown by the molecular relation,

$$56.07 (\text{CaO}) : 100.07 (\text{CaCO}_3) :: \text{wt. CaO required} : \text{wt. of CaCO}_3$$

The relation $\frac{56.07}{100.07}$ is 0.5603 and the two expressions giving the lime required to decompose the carbonate hardness in 1,000 gallons of water are,

$$(A) \frac{\text{Grains per gal. of carbonate hardness, (CaCO}_3) \times 0.5603}{7}$$

$$(B) \frac{\text{Parts per mill. of carbonate hardness, (CaCO}_3) \times 0.05842 \times 0.5603}{7}$$

When A and B are simplified they become,

$$(A_1) \text{ Grains per gal., carb. hardness (CaCO}_3) \times 0.0800 = \text{pounds CaO per 1,000 gal.}$$

$$(B_1) \text{ Parts per mill., carb. hardness (CaCO}_3) \times 0.0047 = \text{pounds CaO per 1,000 gal.}$$

^{112a} The calculated results in these paragraphs refer to pure lime, CaO. Commercial lime, however, is never 100% pure. In preliminary calculations it is usually assumed to be 90% CaO, therefore the results obtained for pure lime must be divided by 0.90 to obtain the corresponding weight of commercial lime.

461. (3) Lime required for the total magnesium. The molecular relation is as follows:

$$56.07 \text{ (CaO)} : 24.32 \text{ (Mg)} :: \text{wt. of CaO required} : \text{wt. of Mg.}$$

The relation of CaO to Mg, $\frac{56.07}{24.32}$, is 2.3055 and the lime required for the magnesium in 1,000 gallons of water is,

$$(A) \quad \frac{\text{Grains per gal. of Mg} \times 2.3055}{7}$$

$$(B) \quad \frac{\text{Parts per mill. of Mg} \times 0.05842 \times 2.3055}{7}$$

These two expressions on simplification become,

$$(A_1) \quad \text{Grains per gal. Mg} \times 0.3293 = \text{pounds CaO per 1,000 gal.}$$

$$(B_1) \quad \text{Parts per mill. Mg} \times 0.1924 = \text{pounds CaO per 1,000 gal.}$$

462. Some chemists prefer to calculate all determinations made as data for softening in terms of calcium carbonate, and consequently such analyses are frequently found. If, for example, the free carbon dioxide, the carbonate hardness, and the total magnesium are all in terms of CaCO_3 , the three values can be added and the sum multiplied by the factor for grains per gal. or parts per million, as the case may be, to get the lime requirement. For the convenience of those who may prefer to recalculate the results as given in this Bulletin the following factors are offered:

$$\text{CO}_2 \times 2.2743 = \text{CaCO}_3$$

$$\text{Mg} \times 4.1147 = \text{CaCO}_3$$

Calculation of Required Soda Ash

463. Since the non-carbonate or permanent hardness in terms of calcium carbonate is the measure of the salts that require soda ash for their precipitation, the calculation is based on the following proportion:

$$106.00(\text{Na}_2\text{CO}_3) : 100.07(\text{CaCO}_3) :: \text{wt. of Na}_2\text{CO}_3 \text{ required} : \text{wt. CaCO}_3$$

The ratio $\frac{106.00}{100.07}$ is 1.0593, and the expressions giving the pounds^{112b}

of soda ash to remove the non-carbonate hardness from 1,000 gallons of water are,

^{112b} For preliminary calculations soda ash is usually assumed to be 99% Na_2CO_3 . The results obtained in the paragraph must therefore be divided by 0.99 in order to obtain the equivalent weight of the commercial soda ash.

$$(A) \quad \frac{\text{Grains per gal. non-carbonate hardness (CaCO}_3\text{)} \times 1.0593}{7}$$

$$(B) \quad \frac{\text{Parts per mill. non-carbonate hardness (CaCO}_3\text{)} \times 0.05842 \times 1.0593}{7}$$

On simplification A and B become,

$$(A_1) \quad \left\{ \begin{array}{l} \text{Grains per gal. non-car-} \\ \text{bonate hardness (CaCO}_3\text{)} \end{array} \right\} \times 0.1513 = \text{pounds Na}_2\text{CO}_3 \text{ per 1,000 gal.}$$

$$(B_1) \quad \left\{ \begin{array}{l} \text{Parts per mill. non-car-} \\ \text{bonate hardness (CaCO}_3\text{)} \end{array} \right\} \times 0.0088 = \text{pounds Na}_2\text{CO}_3 \text{ per 1,000 gal.}$$

Experimental Determination of Lime and Soda Ash

464. Many chemists prefer to treat a measured amount of water with an excess of lime, and after reaction has taken place, determine the excess by titration. The difference between what is left after the reaction and the original amount is the portion consumed by the water. In a similar general way the soda ash quota may also be found. An objection to such a procedure at once suggests itself in that the water is in both cases treated with a large excess of reagent, and, as the procedure usually demands, at a high temperature. It would be expected that less lime and soda would be used under such abnormal conditions, but the opposite seems to be the case. Bartow and Jacobson¹¹³ made a comparative study of such experimental methods and of various schemes for calculating lime and soda additions, and found that the experimental method called for more lime than was obtained by calculating the requirement as described above. They also made a series of tests by treating liter samples of an artificially prepared hard water with varying amounts of lime. Sodium carbonate equivalent to the permanent hardness of this water was added to all samples. The results showed that the amount of lime as calculated from the alkalinity, magnesium, and carbon dioxide, was more nearly correct than that obtained by boiling a portion of water with an excess of lime water and back titrating in order to find how much had been used in precipitating the hardness constituents.

465. These authors also call attention to the frequent discrepancy between the amounts of reagents as calculated in the laboratory and as used in practical softening. Their comparisons show that the large scale treatment of water used more lime and soda ash than were called for by the calculations. They intimate that the difference may be due to the impurities found in commercial lime and soda ash.

466. The particular procedure selected here for illustrating the experimental method is the one by Lord and Demorest:¹¹⁴

¹¹³Analytical Control of Water Softening, Illinois State Water Survey, Bull. No 8, 88.

¹¹⁴Metallurgical Analysis, 5th ed., p. 426.

"To determine the amount of lime and soda ash to add to soften the water proceed as follows: Put in a 250 cc. Jena flask 200 cc. of the water to be tested, add 50 cc. of saturated lime water and heat to boiling. Cool, shake well, and filter through a rapid filter, wash three times with pure, freshly boiled water, and titrate the filtrate with 0.0357N HCl, using methyl orange as indicator. Treat 200 cc. of freshly boiled distilled water in exactly the same way, being careful to use the same amount of methyl orange in both cases and to finish at the same depth of color. The number of cubic centimeters of standard HCl used the second time, minus the number of cubic centimeters used the first time, multiplied by 5 gives the parts of lime to add to a million parts of water.

"Now add to the titrated water in a porcelain dish 30 cc. 0.0714N Na_2CO_3 , heat to boiling, cool, filter, and titrate the excess of soda. The sodium carbonate precipitates both the CaCl_2 made in the first titration and the CaSO_4 , etc., in the water. Therefore, to calculate the amount of sodium carbonate necessary to soften the water subtract from $2 \times 30 = 60$, the total amount of 0.0357N HCl that has been used in both titrations and multiply by 9.45."

467. By far the most rapid and convenient way of getting a check on the calculations of the amounts of lime and soda ash for the proper softening of a given water is to soften liter or gallon portions in the laboratory. Standardized solutions of lime water and sodium carbonate should be employed. They can be used singly or together and the amounts can be varied. In this way not only the softening accomplished by the calculated portions can be found but by a simple cut-and-try scheme the optimum amounts to produce a given result can be worked out.

Greth¹¹⁵ makes the interesting observation that such laboratory scale treatments of water with softening reagents do not give as good results, even with a longer period for subsidence of the sludge, as can be obtained on the large scale. This is, however, no objection to the utility of laboratory experiments.

Calculations from Hypothetical Combinations

468. The majority of industrial water analyses are still reported in terms of the hypothetical combinations (Chap. IV). This is not a satisfactory scheme for use in the calculations of water softening but is of such common occurrence that it demands attention. In such an analysis the hardness constituents are listed as carbonates, sulfates, chlorides, or nitrates of calcium and magnesium, and in calculating the lime and soda ash requirements it is assumed that the carbonates of calcium and magnesium represent the carbonate hardness of the water and that all other salts of these metals make up the non-carbonate hardness. Each item in such an analysis must be calculated separately according to the molecular relations as shown in the reactions, the general rule being as follows: (1) Calculate the lime requirement for

¹¹⁵J. Ind. and Eng. Chem. 3, 15.

the free carbon dioxide, for the calcium carbonate, and the magnesium carbonate, and for all magnesium salts including the magnesium carbonate again. The sum of these items will be the total lime requirement. This is the same as the lime required for the carbonate hardness and for the total magnesium. (2) Calculate the soda ash required for all calcium and magnesium salts, excepting the carbonates. This is the same as the soda ash requirement for the non-carbonate hardness. Finally, it must be added that these rules may give very unsatisfactory results in the case of many analyses; they are to be looked upon merely as the best that can be done under the circumstances. A table of factors for use in such calculations is offered below. In it are also included those factors given above.

TABLE XVIII

Factors for multiplying the analytical results to obtain the pounds of reagent to use for the removal of a given hardness constituent from 1,000 gallons of water.

Hardness constituent	I. Analytical result is in parts per million		II. Analytical result is in grains per U. S. gallon	
	Lime, CaO requirement	Soda ash, Na_2CO_3 requirement	Lime, CaO requirement	Soda ash Na_2CO_3 requirement
CaCO_3	0.0047	0.0088	0.0800	0.1513
CaCl_2	.....	0.0080	.....	0.1364
$\text{Ca}(\text{NO}_3)_2$	.....	0.0054	.....	0.0923
CaSO_4	.....	0.0065	.....	0.1112
CO_2	0.0106	.....	0.1820	.....
Mg	0.0192	.....	0.3293	.....
MgCO_3	0.0056	.....	0.0950	.....
MgCl_2	0.0049	0.0093	0.0841	0.1590
$\text{Mg}(\text{NO}_3)_2$	0.0032	0.0060	0.0540	0.1021
MgSO_4	0.0039	0.0073	0.0665	0.1258

NOTE: The soda ash factor for calcium carbonate refers to non-carbonate hardness, which when given is in terms of calcium carbonate. In the case of the magnesium salts having both lime and soda ash factors, the lime factor is for the precipitation as magnesium hydroxide and the soda ash factor for the precipitation of the equivalent calcium salt left after removing the magnesium.

469. Examples of calculating the lime and soda ash requirements. Suppose that the calcium and magnesium salts in a given analysis are stated as follows, the results being in parts per million:

Magnesium nitrate, $\text{Mg}(\text{NO}_3)_2 = 13$
 Magnesium carbonate, $\text{MgCO}_3 = 105$
 Magnesium chloride, $\text{MgCl}_2 = 13$
 Calcium carbonate, $\text{CaCO}_3 = 120$
 Calcium sulfate, $\text{CaSO}_4 = 82$

According to the statements above, the lime requirement is calculated for twice the magnesium carbonate, for the remainder of the magnesium salts as they stand, and for the calcium carbonate. The soda ash requirement is calculated for all compounds as they stand excepting the carbonates of magnesium and calcium. The necessary arithmetical work and use of the factors are indicated below:

Lime required for	Mg(NO ₃) ₂	=	13 × 0.0032	=	0.0416
"	"	"	MgCO ₃	=	2(105 × 0.0056) = 1.1550
"	"	"	MgCl ₂	=	13 × 0.0049 = 0.0637
"	"	"	CaCO ₃	=	120 × 0.0047 = <u>0.5640</u>

Pounds of lime required for 1,000 gal. 1.8243

Soda ash required for	Mg(NO ₃) ₂	=	13 × 0.0060	=	0.0780
"	"	"	MgCl ₂	=	13 × 0.0093 = 0.1209
"	"	"	CaSO ₄	=	82 × 0.0065 = <u>0.5330</u>

Pounds of soda ash required for 1,000 gal. 0.7319

470. The methods illustrated in Table XII, paragraph 91, can also be adapted to calculations involving the breaking up of hypothetical combinations.

How to Determine whether a Water is Properly Treated

471. Even with correct analyses of the raw water always at hand and correct calculations of the amounts of lime and soda ash used it is necessary from time to time to apply the check of an examination of the treated water. This is especially true of those cases in which satisfactory treatment is not obtained.

472. The methods of examining the softened water are plainly suggested by the various chemical situations that may arise as the result of correct additions of lime and soda ash, or of the use of too much or too little of these reagents. An inspection of the various possible conditions shows that a deviation from the proper amounts of lime and soda ash results in a change in the relative caustic and carbonate alkalinity of the treated water and in its total hardness. Other differences are also present, notably variations in permanent hardness and magnesium, but these seldom need to be measured. The determinations therefore that should be made on the treated water are:

- I. Titration with standard acid using phenolphthalein as indicator = P.
- II. Titration using methyl orange = M.
- III. Determination of total hardness = H.

This examination should be made according to the methods in Chapter V, and the results should all be calculated to a common basis, best as parts per million of calcium carbonate.

473. There might be mentioned in this connection a qualitative experiment by which the presence of caustic alkalinity can be determined. If a few drops of barium chloride solution is added to a water reddened by phenolphthalein the red color will be discharged at once if caused by normal carbonates alone because the CO_3 ions will be precipitated as barium carbonate and an equivalent amount of soluble chloride will be left. If, however, caustic alkalinity due to free calcium or sodium hydroxide is present the red color of the indicator will not be destroyed.

474. In most cases the determination of P and M only need be made. Indeed some routine directions for the examination of the treated water do not include finding the total hardness or the H value, but depend entirely upon the absolute values of P and M and upon the ratio of P to M. Beginners will do well, however, to determine the total hardness, at least until they have grown in experience.

The following gives in condensed form the commoner results of variations in dosage of lime and soda ash:

475. I. Correct amounts of lime and soda ash. The treated and settled water will be a saturated¹¹⁶ solution of calcium carbonate and magnesium hydroxide together with whatever colloidal calcium carbonate may be present. This latter will gradually precipitate if the softened water stands a long time. If just the calculated portions of lime and soda ash are added the reactions will not be completed, and consequently a little of both carbonate and non-carbonate hardness will be present. This residual hardness will contain a larger proportion of magnesium salts than was in the raw water. The amount of total hardness left after treatment in the cold with the theoretical doses of lime and soda ash will vary greatly according to conditions. The minimum attainable is from 45 to 50 parts per million, or about 3 grains per gallon. Under unfavorable conditions, nearly twice as much may be left in the water. The following are apparently some of the determining factors:

476. The harder the raw water is, the higher may be the hardness left after treatment with the calculated lime and soda ash. This is probably due to the solvent action of the large amounts of soluble salts that would be in such a water.

477. The greater the organic matter in the raw water, the higher may be the hardness left in the treated water. Protective colloid effects offer a plausible explanation for this.

478. The higher the magnesium salts in the raw water, the higher may be the hardness left in the treated water. This is in harmony with the well-known fact that the magnesium salts are more difficult to remove than those of calcium.

¹¹⁶This does not mean a saturated solution of calcium carbonate and magnesium hydroxide such as would result from shaking an excess of these substances in distilled water but a solution of them in a water containing the variety of soluble substances that would normally be in a natural water after softening.

479. In such a theoretically treated water H may run from 45 to 75, M from 25 to 40, and P will be approximately half M.¹¹⁷

480. If it is desired to push the cold softening to its limit of about 50 parts per million of total hardness in the treated water, an over-dose of lime and soda ash must be used if the raw water is very hard, over 200 parts per million, for example. The same may be true in the case of raw waters containing organic matter or having a high content of magnesium. The chemical effect of the over-dosage will be the presence of a little caustic alkalinity and a slight excess of sodium carbonate in the water. H in this case will be 50 or less; M will be higher than H, and may amount to 100 or more; and P will be more than half M.

481. II. Too much lime; soda ash correct or in excess. Water will be a saturated solution of calcium carbonate but will contain little magnesium salt. Caustic alkalinity will be present, recognizable by the fact that P will be greater than half M due to the excess of calcium hydroxide or, if too much soda ash was used, to caustic soda. In this latter case sodium carbonate may be present.

H will be lower than normal for the raw water. M will be higher than H and P will be more than half M.

482. III. Too much lime and too little soda ash. Water is a saturated solution of calcium carbonate and low in magnesium. There will be caustic alkalinity due to calcium hydroxide.

H will be high in proportion to the excess of lime, and on account of the deficiency in soda ash. M will also be high in proportion to the excess of lime, and P will be more than half M.

483. IV. Too little lime; soda ash correct or deficient. Water is a saturated solution of calcium carbonate and contains magnesium bicarbonate, carbonate, sulfate, etc. If the deficiency in lime is low there will be little or no bicarbonate. The total hardness will be high; higher if too little soda ash was used. P will be less than half M. H will be high and greater than M in proportion to the deficiency of soda ash.

484. V. Too little lime; soda ash in excess. Water will be same as IV, with respect to Mg salts. Hardness will be high but lower than in IV due to the action of excess of soda ash. Compensating effects of excess of soda ash and too little lime may make hardness normal. Water will contain sodium carbonate.

P will be half M. H will be high unless compensating effect of excess of soda ash lowers it. With a large excess of soda ash M will be larger than H.

485. VI. Too little soda ash; lime correct. Water is a saturated

¹¹⁷It is with great hesitation that these figures are put down. They are to be looked upon as crude approximations only.

solution of calcium carbonate and magnesium hydroxide and will contain calcium salts as permanent hardness.

P will be less than half M. H will be high and greater than M.

486. VII. Too little soda ash; too little lime. Same as IV.

487. VIII. Too little soda ash; too much lime. Same as III.

488. IX. Too much soda ash; lime correct. Water is a saturated solution of calcium carbonate and magnesium hydroxide and contains sodium carbonate.

P will be half M. H will be low and less than M.

489. X. Too much soda ash; too much lime. See II.

490. It would be comforting if it were possible to set up arbitrary limits for H, M, and P, as given above, and specify that certain values mean correct or incorrect additions of the softening chemicals, but the author has not the courage to do it. Coward-like he offers the suggestions above and asks for the use of common sense in applying them to specific cases. The laboratory methods of softening referred to in 467 offer opportunities to try the effect of varying the dosage, and thus quickly arriving at the correct, or approximately correct, amounts of lime and soda ash, which then can be given a finer adjustment in the softener.

Control of Softening by Persons without Chemical Experience

491. It is obvious that every water softener cannot have a chemist in charge, and it is, therefore, a practical question to raise, can the engineer or some other employee make tests on the water to determine whether the softener is functioning properly? The answer is a qualified affirmative. The average intelligent workman, and certainly the chief engineer or his assistant, can be taught to carry out the simple chemical operations involved in determining the values of H, M, and P, as given above. The apparatus and solutions used must, however, be furnished by a chemist, and a chemist should also make periodical examinations to see that everything is working properly, and in case of serious trouble the chemist alone is able to find the cause. Most if not all manufacturers of softeners furnish detailed directions for the control work. Such sets of routine directions for the operator of a softener are also occasionally found in the technical journals. One by Clark is in the *Chemical and Metallurgical Engineer*, Vol. 19, page 674.

Cost of Water Softening

492. The costs of water purification like those of any industrial operation are distributed over such items as investment in equipment,

interest on investment, deterioration, repairs, maintenance, attendance, power, and materials used. The writer not being an engineer—not even an efficiency one—does not feel able to discuss all of these points, and will content himself, therefore, with a few general observations. Water softening costs are usually computed on the basis of 1,000 gallons of water. Equipment and attendance per 1,000 gallons is less the larger the capacity of the softener. The cost of chemicals is proportional to the amount of hardness removed and to the volume of water treated. The nature of the hardness also affects the cost of chemicals in the sense that it is cheaper to remove a unit of carbonate hardness than one of the non-carbonate kind because lime is employed instead of the more costly soda ash.

493. In general, the softening of water is a matter of a few cents per 1,000 gallons, and runs under normal business conditions from one or two cents up. The cost that a given set of conditions will justify is measured not so much by the greater comfort in using the softened water as by the savings effected over the cost of using a hard water. In the boiler room the use of a properly softened water will reduce to an almost negligible amount the enormous expenses entailed by hard water. Such items as cleaning out scale and replacing pitted tubes will almost disappear. Less fuel will be needed because there will be no scale to act as an insulating layer between the source of heat and the water. Smaller boiler equipment will carry the load because individual boilers will not be out of commission for long periods of time for cleaning and repairs. If boiler compound has been used it can be discontinued. These savings are large, and where a very hard water—such as is common over Ohio—has been in use, they may amount in a year or two to the cost of a softener. In laundries, in addition to the savings in the power plant, there is another large item involved in the soap consumption. The removal of iron is also a point of interest in laundry work because of the brown stains produced when that element is present. In other industries such as paper making, starch manufacturing, tanning, dyeing, and the like, pure water also is in demand, and its use brings material economies and adds to the quality of the finished product.

Softening by Heating. Feed Water Heaters

494. Since the introduction of cold water into a steam boiler while it is in operation is wasteful of heat, it is a common practice to provide preheaters. These are of two types, open and closed, which means that one form is an open vessel in which the water remains at atmospheric pressure and escaping gases pass out into the air, and the other is a closed vessel in which the water is not exposed to the air and in which a pressure greater than that of the atmosphere can develop. In both forms there occurs a certain amount of purification, which is

the greater the higher the temperature of the water, the longer it is kept at a high temperature, and the higher the temporary hardness is.

495. The degree of purification in any form of heater is small in comparison with softening by lime and soda ash or by exchange silicates. This is because the temporary hardness only is affected to any marked extent, and because the water as a rule is not in the heater more than a few minutes, which is not sufficient for the completion of the necessary chemical changes. Heaters are probably more useful as fuel economizers than as purifiers. Conflicting statements are plentiful concerning the amount of scale-forming constituents removed. W. M. Booth¹¹⁸ says that the best heaters may remove from 50 to 75 per cent of the carbonate hardness. This is perhaps too optimistic. A private communication to the author from an agent of one of the larger manufacturers of open heaters states that his company used to believe that about 75% of the temporary hardness of the feed water was removed in the heater, but after conducting a series of experiments it was learned that this belief was not well founded. The communication carries an additional statement to the effect that a satisfactory removal of carbon dioxide and oxygen is effected by heating the water approximately to its boiling point. This is an important item in feed water purification, especially in regard to the removal of dissolved oxygen, since this would greatly lower the corrosive action of the water. Greth¹¹⁹ says that if an exhaust steam heater were effective in removing the temporary hardness it would require almost constant cleaning, which would defeat its purpose as a heater. A similar outspoken objection to the preheater as a softener is made by Read,¹²⁰ who says that the preheater is not a sludge tank. Read and Greth are also authorities for the statement that in a closed live steam heater all of the temporary hardness separates but only a part of the permanent hardness. The author rather questions this statement because there is scarcely time enough in the passage of the water through the heater for the completion of the necessary chemical reactions.

Chemical Changes Due to Heating

496. If water containing temporary or carbonate hardness is exposed in an open vessel carbon dioxide (CO_2) at once begins to escape, even in the cold. This loss of carbon dioxide disturbs the equilibrium existing between it and the bicarbonates of calcium and magnesium in the water, with the result that some bicarbonate decomposes to restore the carbon dioxide lost. This freshly formed gas will also pass

¹¹⁸Chemical Engineer 11, 8.

¹¹⁹Water Purification Facts for Steam Users. A paper read before the Rochester Engineer's Club, Feb. 10, 1910.

¹²⁰Boiler Waters, their Chemical Composition, Use, and Treatment, University of Texas Bulletin No. 1752, page 53.

out of the water, again disturbing the balance, and so on till all of the bicarbonates have decomposed. The reactions are as follows:



At or near the boiling temperature these reactions go rapidly and consequently a 20 to 30 minute period of heating will destroy the temporary hardness constituents.

497. The usual statement that both calcium and magnesium carbonates precipitate on heating a water containing the bicarbonates of the two metals is not true of the majority of natural waters. When the ordinary boiler water is heated in an open vessel calcium carbonate alone is precipitated even if the water contained magnesium bicarbonate. The reason for this lies in the fact that the average natural water contains a great deal more calcium than magnesium and there is therefore sufficient calcium to react with all of the carbonate ions. Since calcium carbonate is more insoluble than magnesium carbonate, it precipitates first and continues to come down till all of the carbonate ions are used up. This calcium which takes the place of magnesium comes from the permanent hardness, the sulfate, chloride, and nitrate of calcium in the water, and consequently a corresponding amount of the sulfate, chloride, and nitrate of magnesium takes its place. A more accurate chemical statement of the situation would be, that owing to the greater concentration of the calcium ions and the greater insolubility of calcium carbonate, the solubility product of calcium carbonate is reached first, and therefore it precipitates. In the case of waters that do not contain an excess of calcium salts, some magnesium carbonate will also precipitate. Finally it should be added that heating drives out of a water not merely the carbon dioxide but also other dissolved gases. This fact is important in the purification process because oxygen, which is nearly always present in a feed water, and hydrogen sulfide, which is sometimes present, are at least partially eliminated in the open heater, thus reducing the corrosive action of the water.

498. If a closed heater is used employing live steam from the boiler as a source of heat there will be a partial precipitation of calcium sulfate along with the carbonates. This is due to the higher temperatures attained in this type of heater, and to the fact that the solubility of calcium sulfate decreases with increase of temperature.

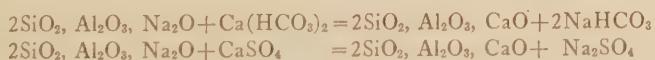
Softening with Zeolites

499. Softening with zeolites consists in passing the hard water through an artificially prepared exchange silicate which has the property of taking out all of the calcium and magnesium and giving up an equiva-

lent of sodium salt. After some time this action ceases and the silicate is then regenerated by treating it with a solution of salt, sodium chloride. An exchange takes place in the reverse direction. Calcium and magnesium salts go into solution and sodium compounds enter into the solid zeolite. The process can be repeated almost indefinitely without loss of the original material.

500. The discovery of this interesting process was made by R. Gans, chemist of the German Geological Survey. Gans noted that certain natural minerals called zeolites had the property of giving up their sodium in exchange for calcium and magnesium when placed in a water solution of salts of these bases. Through further study he developed an artificial zeolite with a higher exchange power than the natural ones. This he called "*Permutit*."¹²¹ It is a hard, tough, porous solid, completely insoluble in water. The use of this water softening material developed and a company was organized in America for handling it. This organization known as "The Permutit Company" issues the usual printed matter, and it is from one of their pamphlets entitled "The Chemistry of Permutit" that much of the following is taken. Zeolite softening in the United States is however not confined to the use of permutite. A natural zeolite for example is mined here and refined for the purpose. The author has made no search for zeolite softening concerns other than the Permutit Company, but it happens that the advertising matter of two such companies has fallen into his hands. Their names are The Vaile-Kimes Company, Dayton, Ohio, and Crane and Company, Chicago. Most of the published papers, however, that deal with zeolite softening are records of experiments with permutite and, therefore, the references are of necessity to them.

501. "Synthetic exchange silicates may be produced by precipitation or by fusing. In the latter, feldspar, kaolin, pearl ash, and soda are fused together in definite proportions. The glass thus produced is crushed and is then lixiviated to remove the soluble silicates." The formula, $2\text{SiO}_2, \text{Al}_2\text{O}_3, \text{Na}_2\text{O}, 6\text{H}_2\text{O}$, is offered as at least approximately correct for this synthetic zeolite. It will be noticed that no potassium appears in this formula although pearl ash was used. It was probably added to lower the melting point of the mixture¹²² and may also have an effect in producing a product of suitable porosity. The following are typical reactions:



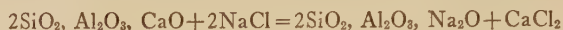
The corresponding magnesium compounds can be substituted for

¹²¹The author hopes that American chemists will follow the lead of Chemical Abstracts and write permutite as an English word instead of using the original German "*Permutit*." He hopes further that the accent will presently settle permanently upon the first syllable.

¹²²D. D. Jackson, J. Amer. Water Works Assoc. 3, No. 2, p. 430.

the calcium ones in the above equations. It is to be noted that both the carbonate and non-carbonate hardness can be removed.

502. In course of time the sodium in the permutite is exhausted and no further softening will take place till it is regenerated. This is done by treating the solid permutite with an 8 to 10% solution of salt. The sodium of the salt quickly takes the place of the calcium or magnesium, the latter going into solution as chloride according to the following:



503. In practice the permutite which is an insoluble, granular solid, is put into a vertical tank of suitable size for the volume of water to be treated. This tank is equipped with the necessary pipes and valves for controlling the flow of water and for introducing and washing out the regeneration salt solution. There is no sludge of precipitated material and, therefore, no provision need be made to handle it or time spent in waiting for the water to clear. If, however, the original water is turbid with clayey matter it must be clarified or the bed of permutite will become clogged. The depth of the layer of permutite and the rate of flow of the water through it are of course determined by the hardness of the water. The harder the water the slower must be its rate of flow or the thicker must be the bed of permutite.

Rate of Softening with Permutite

504. The rate of softening with permutite is high as is shown by Hoover and Scott¹²³ who experimented with the Scioto River water, a typical Ohio supply. The raw water had a carbonate or temporary hardness of 180 parts per million and a non-carbonate or permanent hardness of 200, thus giving a total hardness of 380. On passing through a layer of permutite at the rate of seven feet per hour this water was completely softened. Jackson¹²⁴ says that the reaction time of softening by permutite is about two minutes for soft water, three to six minutes for medium hard water, and seven to twelve minutes for a very hard water. By reaction time he evidently means the time of contact of the water with the permutite. This is ten to twenty times faster than the rate of softening by the lime-soda process when time for settling of the sludge is taken into account.

505. The net time for permutite softening is, however, conditioned by the period of regeneration. Roughly speaking, the time required to reactivate the permutite is about the same as the period of softening, that is, it will take as many hours to regenerate as the permutite has been used for softening. This would mean on a one unit plant that it would soften by day and be regenerated at night.

¹²³Ohio Public Health Journal 6, 143.

¹²⁴J. Amer. Water Works Assoc. 3, No. 2, 426.

Character of Water Softened by Permutite

506. The most striking characteristic of water softened by permutite is that it literally has a zero hardness, or a near approach thereto. It is the only practical way except by distillation for attaining this end. Samples 407 to 411 inclusive, of this Bulletin, are examples of permutite softened water. The total hardness is not literally zero but is nearly so.

507. Reference to the equations above will show, however, that the softened water contains sodium salts equivalent to the original amounts of calcium and magnesium, and since the equivalent weight of the sodium salts will average nearly 1.5 times that of the calcium and magnesium compounds in terms of calcium carbonate, it follows that for each part per million of hardness in the raw water there will be about 1.5 parts per million of sodium salts in the softened water. This will be sodium bicarbonate for the temporary hardness and sodium sulfate, chloride, and nitrate for the permanent hardness. The presence of the sodium salts, however, has no effect excepting to increase the tendency to foam if the water is used for making steam. The sodium salts are nevertheless no advantage and it would be desirable to eliminate them. This can be done in part by removing the carbonate hardness with lime and then finishing the softening with permutite.

Combining Lime Softening with the Permutite Process¹²⁵

508. Reference to the equations in 391 shows that eliminating the bicarbonates of calcium and magnesium is an ideal industrial chemical process because not only are the undesirable constituents precipitated but also the added reagent. This lime treatment is furthermore the least expensive of the various operations. The resulting product contains only the magnesium and the sulfates, chlorides, etc., constituting the original non-carbonate hardness. On passing this partially softened water through permutite, zero hardness is attained, but with the addition of much less sodium salt to the water than if the whole softening had been accomplished with permutite.

Operation of a Zeolite Softener

509. When zeolite alone is employed the sole reagent consumed is the salt used in regeneration. This is one of the least expensive of chemical substances and therefore adds little to the costs. An ordinary workman can be taught to operate the valves and to prepare the salt solution, consequently attendance costs are a minimum. Chemical services are not needed because the permutite automatically softens water of whatever degree of hardness and will handle a water of variable composition as well as one that is constant. When, however, the zeolite process is combined with lime softening more control work becomes necessary and the services of the chemist must be enlisted.

¹²⁵The Permutit Company has a patent on this procedure.

Clarification and Decolorization of Water

510. For many industrial uses a clear, colorless water is more in demand than a soft one, and for personal use our aesthetic sense requires the same properties. The milk which nourishes man in his early years is a liquid of high turbidity, and some of the beverages of his mature life are highly colored, but he consistently demands that the water he uses shall be perfectly limpid and free from suspicion of tint. Moreover, freedom from turbidity and color is a desirable prerequisite for other forms of purification and, therefore, clarification and decolorization are among the most important operations of water treatment. They can be discussed together because the same methods are used for the removal of both color and turbidity.

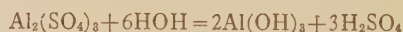
511. Ohio is a clay country and her waters are therefore turbid, but there are few examples of colored waters like those of many New England streams, the color of which is due to dissolved vegetable matter.

512. The heavier particles in a water are most economically disposed of by sedimentation. This alone, however, is not sufficient for the clayey water of Ohio though it is an excellent preliminary treatment.¹²⁶

513. In order to insure a clear water in a reasonable time a so-called coagulant must be added. This is a substance such as a soluble salt of aluminium or iron which will form a gelatinous precipitate. This precipitate entangles the finely divided solid matter constituting the turbidity and adsorbs the coloring matter if the water is colored. The removal of the precipitate then by settling or filtration removes the turbidity and the color. A simple rule holds: Other things being equal, the more turbidity and the more color there is to be removed the more coagulant must be employed for the removal. Much stress must be put upon that phrase, other things being equal.

514. Aluminium sulfate, called "alum" in water parlance, and ferrous sulfate, copperas, are about the only substances employed as coagulants. Of these the copperas is the cheaper but the alum usually gives better results and is free from the trouble of producing stains which is a fault of the iron compound when not properly handled.

515. When aluminium sulfate dissolves in water there is a reaction between the aluminium ions and the hydroxyl ions of the water which results in the precipitation of aluminium hydroxide according to the equation,



516. This reaction is reversible, that is, as it proceeds there is an increasing tendency for it to go in the opposite direction until an equilibrium is reached and no more hydroxide forms. In other words, the concentration of the sulfuric acid soon reaches a point at which the

¹²⁶Elms, J. W., Water Purification.

aluminium hydroxide dissolves as fast as it precipitates. If, however, there is an alkali in the water the acid is neutralized as fast as it forms and all of the aluminium will be precipitated. In waters fairly high in carbonate hardness the soluble bicarbonates serve this purpose. If a water is deficient in carbonate hardness an alkali, lime or soda ash, must be added.

517. Aluminium hydroxide is soluble in both acids and alkalis, and therefore the proper degree of alkalinity must be maintained in the water or maximum results will not be obtained. In actual practice, however, the water chemist does not fix his attention so much upon the point of minimum solubility of the aluminium hydroxide as he does upon its physical properties. He wants a good "floc," that is, a precipitate of aluminium hydroxide which forms quickly in large flakes or flocs and which settles rapidly and filters easily. He wants this condition of flocculation because it is the one under which the alum is most effective in removing color and turbidity. Fortunately the conditions which make for a good floc are nearly the same—perhaps the same—as those for minimum solubility, but exactly what these conditions are is not as yet definitely known.

518. Although the effect on coagulation of each of the variables affecting water treatment is not known, present day knowledge points strongly to the idea that the hydrogen ion concentration or pH value (321) of the water is the dominating one. This means that formation of a good floc is so strongly affected by hydrogen ion concentration that if some condition exists in a water which prevents good flocculation its effect can frequently be overcome by an appropriate change in the hydrogen ion concentration. Whether the concentration should be increased or decreased can not be determined except by experiment, which shows that our knowledge of the situation is still empirical. A scientific theory would indicate in which direction the change should be made.

519. Both laboratory experiment and plant experience seem to point to the existence of a zone in the acid region, from about pH 4.5 to 7.0, outside of which a good floc is seldom obtained. Within that range, however, the pH must be varied until optimum conditions are reached, which is shown by the precipitation of the aluminium hydroxide in large flakes. It must be said, however, that this statement is not of general application. In the majority of the Ohio filtered supplies, for example, the optimum conditions of flocculation are found in the region of pH 7.4 to 8.4.^{126a}

520. The hydrogen ion concentration of the water can be increased, that is, the pH can be lowered by adding more alum (514) or by adding sulfuric acid. Conversely, the hydrogen ion concentration can be

^{126a}Private communication from C. P. Hoover.

lowered or the pH value raised by the addition of lime or soda. The optimum pH value for a given water can be found by experimenting in the laboratory with portions of a liter or more. Standard solutions of alum, acid, and alkali should be used, the stirring should be done by a motor-driven stirrer, the speed of which should be regulated so that the large scale conditions of the plant will be approached,¹²⁷ and the additions of the reagents should be carefully measured. The quickest forming floc may be considered the best one¹²⁸ and the pH of the water at the time of its formation the optimum hydrogen ion concentration. The conditions found by the laboratory experiments should then be confirmed by the large scale operations of the purification plant.

521. Experience shows that remarkable effects can at times be produced by varying the hydrogen ion concentration of a water. Catlett¹²⁹ found in the treatment of many colored waters of North Carolina that the optimum conditions for a good floc were at the surprisingly high acidity of pH 4.3 to 5.0. These conditions must have been obtained by the use of alum because he makes the interesting statement that all of his efforts to lower the pH of the highly colored waters by adding sulfuric acid were unsuccessful. This would seem to indicate that the vegetable coloring matter is a buffer substance. Catlett, however, added sulfuric acid to some of the waters in order to obtain the optimum pH value. In treating the water of the Tar River, for example, he found that by using acid as good a floc was formed by 0.5 a grain per gal. of alum as by 1.5 g. p. g. without acid. This means that the extra alum had been required to acidify the water. Baylis¹³⁰ found by a series of tests on a certain water that "the optimum point, or the point at which the least amount of alum would remove a certain turbidity, was about pH 5.5." He used acid along with alum for the clarification and decolorization of the Baltimore water and found that 0.52 g. p. g. of sulfuric acid and 0.32 g. p. g. of alum were as effective as 1.68 g. p. g. of alum alone.

522. Dissolved vegetable matter in a water (color) usually interferes with coagulation. This has led to efforts to modify the organic matter by a pretreatment with chlorine or bleaching powder. The effect is marked. Better coagulation and consequently better color and turbidity removal is obtained with less alum than if no chlorine is used. An excellent paper on such treatment of water is one by Weston, *J. Am. Water Works Assoc.* 11, 446 (1924).

¹²⁷Baylis, *J. Am. Water Works Assoc.* 10, 365 (1923), says that with due attention to details, plant conditions can be duplicated in the laboratory. He makes the following interesting observation, "Chemists should stop saying that they can not tell from laboratory experiments what to expect in the plant. Such statements are merely a confession that we do not know how to duplicate plant conditions."

¹²⁸Catlett, *J. Am. Water Works Assoc.* 11, 892 (1924), used this criterion and cites Clark and Theriault as being of the same opinion.

¹²⁹Catlett, *J. Am. Water Works Assoc.* 11, 892 (1924).

¹³⁰*J. Am. Water Works Assoc.* 10, 365 (1923).

523. Laymen who may be reading these pages should not be alarmed at learning that the drinking water supply of their city is dosed with such substances as alum, sulfuric acid, and chlorine. The amounts added are, in the first place, very small and, in the second place, the original substances have either been removed by filtration or have been transformed by natural chemical reactions into harmless compounds before the water reaches the consumer.

524. It must not be assumed that the pH value of a water is the only variable that affects coagulation. In March, 1923, the Committee on Colloidal Chemistry¹³¹ of the American Water Works Association summed up the matter in the following paragraph:

"The coagulation of suspended or dissolved materials in a water is not a simple problem. While in any single sample of water there is undoubtedly a definite range of hydrogen ion concentration for maximum precipitation, under given conditions of free carbon dioxide and bicarbonate alkalinity, other factors, some of which are not chemical, enter into the problem. Of these, temperature, rate of mixing, degree of dilution, concentration and kinds of electrolytes present, nuclei, organic acids, and the amount and character of the suspended matter greatly affect precipitation. Furthermore, there are specific reactions between aluminium hydroxide and color and suspended matter, on which the pH value may or may not throw light."

Removal of Iron and Manganese from Water

525. Many Ohio ground waters contain iron in the form of soluble bicarbonate. Such waters may be clear when first pumped but rapidly become cloudy on exposure to the air, probably due to loss of carbon dioxide. The particles constituting the turbidity are at first white but gradually change to a yellow color and finally coagulate in the form of a brown precipitate. A very small amount of iron, as little as one or two parts per million, will form a bulky precipitate which not only renders the water unsightly and unfit for many industrial uses but also is sufficient to stop up the pipes. Manganese in a water behaves in the same way and is even harder to dispose of than iron. Fortunately, there are few such waters in Ohio.

526. The cheapest way of removing iron from a water is by aeration and sedimentation. The aeration can be accomplished by spraying the water into the air, by blowing air into the water, or by causing the water to fall in a cascade or trickle through a bed of coarse material like stone or coke. The method to be employed is an engineering problem peculiar to the specific situation.

527. Special permutites (500) are also made for the removal of iron and manganese from water and their use should be investigated when a problem of this sort is at hand.

¹³¹J. Am. Water Works Assoc. 10, 277.

PART II

THE CHEMICAL CHARACTER OF THE SURFACE WATERS OF OHIO¹

The analyses in Part II are taken by permission from the Reports of the State Board of Health of Ohio and it is a pleasure to record here this example of the cooperation of another important scientific agency of the State with the Geological Survey.

These analyses were made by the State Board of Health to determine the wholesomeness of the waters for drinking. They are, in other words, sanitary analyses (19) and therefore they do not include so many of the mineral constituents as are found in the analyses of the ground waters in Part III. In compiling them for this Bulletin only those determinations were used that convey an idea of the physical character of the water and its suitability for industrial uses. Where necessary the values were recalculated to bring them into conformity with those of Part III, except that no attempt was made to compute the grains per gallon corresponding to the parts per million.

Since most of these analyses were made over 25 years ago, the question naturally arises as to whether they represent the waters as they are today. The answer to this is a qualified affirmative. In the great majority of the rivers these old analyses represent the water as it is today. If a stream has not been receiving an increasing amount of industrial waste the average mineral content of its water will remain constant over long periods of time. In cases like the Mahoning River, however, the situation is different. The results given for its lower stretches, where it now receives the industrial sewage of numerous steel mills, have only a historical value at present.

Part III also contains the analyses of many samples of river water. They can not, however, be compared with those of Part II, because the waters of a stream vary so much with seasonal changes and with weather conditions, that any one sample might deviate very much from the average.

¹In addition to the analyses of the surface waters of the State, the Reports of the Ohio State Board of Health also contain hundreds of analyses of well waters. These results are scattered through the annual volumes, mostly under the heading, "Examination of Miscellaneous Waters from Private Supplies and Special Sources."

In the volumes of the Board of Health Reports the analytical results are discussed at length and those who may be seeking detailed information about the character of the Ohio surface waters should consult these reports:

In Report for 1898. Mahoning River, Olentangy River, Scioto River, and Little Scioto River.

In Report for 1899. Auglaize River, Blanchard River, Maumee River, Ottawa River, St. Joseph River, St. Marys River, and Sandusky River.

In Report for 1900. Apple Creek, Killbuck Creek, Kokosing River, Licking River, Mohican River (Black Fork), Mohican River (Rocky Fork), Muskingum River, Nimishillen Creek, Nimishillen Creek (West Branch), Stillwater Creek, Tuscarawas River, Walhonding River, and Wills Creek.

In Report for 1901. Buck Creek, Greenville Creek, Mad River, Miami River, Little Miami River, Little Miami River (East Fork).

In Report for 1902. Lake Erie and Ohio River.

Under date of April, 1915, the State Board of Health issued a special volume, prepared by M. Z. Blair, entitled Report of Public Water Supplies on the Ohio River. This report gives a series of analyses along the course of the Ohio from New Martinsville, W. Va., to Cincinnati, Ohio. The samples were taken between Oct. 20 and Nov. 3, in 1913.

The chemical work and field observations taken from the report for 1898 were carried out by Professors N. W. Lord and A. M. Bleile of The Ohio State University. The results from the subsequent volumes were obtained by various members of the staff of the State Board of Health.

The chemical methods used in obtaining the analytical results reproduced in Part II are given in detail in the reports for 1898 and for 1899. In the subsequent reports only new methods or modifications of the old ones are to be found. It is sufficient here to record that the results for nitrate, chloride, hardness, and total solids may be compared with the values for the same constituents as given in Part III.

The determinations of color as given in Part II were made by the original platinum-cobalt method of Hazen (*Am. Ch. Jour.* 14, 300). The numerical values as given should be multiplied by 100 to obtain the results in the modern terms of parts per million of platinum.

The quantitatively expressed results for turbidity were all obtained by the turbidity rod and wire method of Hazen (*Mass. State Board of Health Report for 1890, Part 2, p. 735*), and are given in reciprocals of the distance in inches to which the wire was immersed when it was just obscured by the turbidity of the water: e. g. if the wire was 0.5 in. under water, the turbidity was called 2, if 2 in. under, the turbidity was 0.5, etc. There are, however, two exceptions to this method of representing turbidities, namely, the results for Lake Erie and the Ohio River. These are given in terms of the silica standard, the conversions from the data obtained by the rod having been made by the method of Whipple (*Tech. Quar. for Sept., 1900, p. 285*).

TABLE XIX
SURFACE WATERS OF OHIO

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
APPLE CREEK. Samples collected in 1899.					
Wooster, above town.....	May 4	.10	.07 ¹	Slight	None
" " "	May 30	.40	.85	Considerable	Earthy
" " "	June 28	.10	.06 ¹	Very slight	Vegetative
" " "	July 19	.15	.09	" "	"
" " "	Aug. 18	.05	.06 ¹	" "	None
" " "	Sept. 19	.20	.24	Considerable	Earthy
" " "	Oct. 12	.10	.06 ¹	Very slight	None
" " "	Nov. 16	.40	.12	Slight	"
Average.....		.19	.19		
AUGLAIZE RIVER. Samples collected in 1898.					
Defiance, above town.....	July 22	.2	Distinct	Slight	None
" " "	Aug. 23	.35	Slight	"	Faint musty
" " "	Sept. 27	.5	Decided	"	Woody
" " "	Oct. 25	.4	Distinct	"	Musty
" " "	Nov. 15	.28	Decided	Considerable	Earthy
Average.....		.35			
BLANCHARD RIVER. Samples collected in 1898.					
Findlay, above town.....	July 21	.2	Slight	Slight	None
" " "	Aug. 25	.28	None	"	Musty
" " "	Sept. 26	.5	Decided	"	Peculiar, bad
" " "	Oct. 24	.45	Slight	Very slight	Very disagreeable
" " "	Nov. 14	.32	Decided	Considerable	Peculiar
Average.....		.35			
Findlay, below town.....	July 21	1.00	Slight	Slight	Bad, oily
" " "	Aug. 25	.2	None	Considerable	Musty
" " "	Sept. 26	.45	Decided	Slight	Peculiar, bad
" " "	Oct. 24	.3	Distinct	"	Foul
" " "	Nov. 14	.3	Decided	Considerable	Peculiar
Average.....		.45			
BUCK CREEK. Samples collected in 1900.					
Springfield, above town.....	April 16	.10	.05	Slight	None
" " "	May 24	.10	.10	Considerable ²	Vegetative
" " "	June 20	.23	.09	Slight	Faint earthy
" " "	July 10	.15	.23	Considerable	" "
" " "	Aug. 9	.17	.14	Slight	Vegetative
" " "	Sept. 5	.13	.16	"	"
" " "	Oct. 3	.15	.10	"	Faint vegetative
" " "	Nov. 3	.17	.05	Very slight	None
Average.....		.15	.11		

¹Turbidity rod on bottom of stream with wire still visible.

²Floating vegetation which had settled to bottom.

TABLE XIX
SURFACE WATERS OF OHIO

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.2	2.4	133.4	36.2	169.6	224
0.5	3.6	52.9	5.2	58.1	263
0.1	3.7	151.7	.....	151.7	220
0.2	3.4	149.0	20.6	169.6	240
0.3	2.2	157.8	9.8	167.6	250
0.1	1.6	155.2	6.0	161.2	311
Trace	1.7	176.6	20.8	197.4	260
0.4	2.1	145.4	34.4	179.8	268
0.2	2.6	140.2	16.6	156.8	254
1.3	106.6	142.8	86.4	229.2	455
7.5	95.0	126.0	37.0	163.0	580
11.6	117.1	128.9	72.4	201.3	870
2.0	71.4	158.2	61.6	219.8	602
39.8	27.8	139.0	43.4	182.4	385
12.4	83.6	139.0	60.2	199.2	578
1.70	19.5	130.2	154.6	284.8	678
81.5	165.5	50.6 ¹	162.1	212.7	1222
27.9	449.5	67.9	125.2	193.1	1258
36.7	144.5	138.0	98.6	236.6	725
62.4	44.9	128.6	72.0	200.6	529
42.0	164.8	82.8	122.5	205.3	882
1.4	107.7	133.4	147.2	280.6	830
68.6	127.3	44.0 ¹	158.4	202.4	962
17.3	350.9	70.1	111.4	181.5	1302
40.7	266.0	91.4	125.6	217.0	1073
57.5	34.0	128.8	58.6	187.4	536
37.2	177.2	94.9	119.8	214.7	941
3.7	0.4	242.0	2.98	244.98	407
4.9	0.3	244.4	27.2	271.6	431
3.7	0.2	268.0	12.0	280.0	438
4.9	0.4	260.2	30.0	290.2	463
7.1	Trace	227.6	29.0	256.6	384
6.6	Trace	239.4	1.8	241.2	386
7.1	0.4	219.4	3.0	222.4	425
9.3	0.5	249.4	13.2	262.6	399
5.8	0.3	243.8	18.2	262.0	417

¹Acid

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
LAKE ERIE ¹ . Samples collected in 1901.					
Ashtabula, high pressure.....	April 25	.22	37	Slight	None
" " "	June 19	.12	Trace	Very slight	Faint
" " "	July 10	.20	"	Trace	"
" " "	Aug. 6	.9	Very slight	Very slight	Faint vegetative
Ashtabula, low pressure.....	April 25	.18	21	Trace	None
" " "	June 19	.10	Slight	Very slight	Faint
" " "	July 10	.20	"	" "	Vegetative
" " "	Aug. 6	.9	Trace	Trace	None
" " "	Aug. 31	.8	"	"	"
" " "	Oct. 2	.12	Very slight	Very slight	"
" " "	Oct. 29	.12	" "	" "	"
Average.....		.14			
Conneaut, Lake Erie.....	April 26	.10	Trace	Trace	None
" " "	June 19	.10	"	"	"
" " "	July 10	.8	"	Very slight	"
" " "	Aug. 13	.5	"	Trace	Vegetative
Average.....		.8	"		
Conneaut, hydrant.....	April 26	.10	Trace	Trace	None
" "	June 19	...	...	.....	.....
" "	July 10	.5	"	None	"
" "	Aug. 13	Trace	None	"	"
Average.....		.5			
Painesville, Lake Erie.....	April 25	.23	111	Considerable	None
" " "	June 24	.23	58	Slight	Trace
" " "	July 10	.22	178	"	Peculiar
" " "	Aug. 7	.18	78	"	None
" " "	Oct. 24	.12	136	"	"
Average.....		.20	112	"	
Painesville, hydrant.....	April 25	.16	Trace	Trace	None
" "	June 24	.8	None	None	"
" "	July 10	.5	"	"	"
" "	Aug. 7	.8	Trace	Trace	"
" "	Oct. 24	.8	None	None	"
Average.....		.9			
Painesville, hydrant-special....	Mar. 10	.35	58	Very slight	Vegetative

¹Turbidity is given in terms of silica standard. See page 161.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
None	4.3	81.	12.	93.	192
Trace	4.9	91.	.....	91.	170
"	6.7	86.	.....	86.	239
0.2	5.3	94.	.....	94.	163
None	4.3	78.	.....	78.	140
Trace	4.3	91.	.....	91.	175
"	6.3	86.	.....	86.	189
0.2	5.5	93.	.....	93.	152
Trace	5.2	93.	.....	93.	129
None	4.3	97.	.....	97.	155
0.5	5.4	91.	.....	91.	139
0.1	5.1	89.	.....	89.	168
None	4.2	72.	.....	72.	150
0.9	4.9	85.	.....	85.	161
Trace	5.1	87.	12.	99.	176
0.4	4.8	96.	22.	118.	160
0.4	4.8	85.	.....	85.	162
None	4.8	66.	30.	96.	163
0.5	.....	.....	.....	.....	...
Trace	6.0	88.	28.	116.	175
0.4	4.7	89.	14.	103.	158
0.2	5.2	81.	24.	105.	165
None	3.0	67.	None	67.	298
Trace	7.5	89.	.....	89.	215
"	7.0	81.	.....	81.	241
0.5	5.5	92.	.....	92.	182
0.5	5.6	91.	.....	91.	248
0.2	5.7	84.	.....	84.	237
None	6.5	72.	32.	104.	248
Trace	7.5	103.	.....	103.	223
"	7.8	97.	.....	97.	167
0.4	5.7	98.	.....	98.	181
0.4	5.4	96.	.....	96.	158
0.1	6.6	93.	.....	93.	195
3.0	2.5	51.	26.	77.	161

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity ¹	Sediment	Odor
LAKE ERIE ¹ —Concluded.					
Port Clinton, Lake Erie at intake.....	April 24	.20	.923	Slight	None
“ “ “.....	June 18	.15	.78	“	Fishy
“ “ “.....	July 10	.25	.92	“	Peculiar
“ “ “.....	Aug. 7	.23	Very slight	“	Faint
Average.....		.21	364		
Port Clinton, hydrant.....	April 24	.25	.666	Considerable	None
“ “ “.....	June 18	.15	.116	Slight	Faint and fishy
“ “ “.....	July 10	.27	.83	“	Peculiar
“ “ “.....	Aug. 7	.21	Trace	Trace	Faint
Average.....		.22	288		
GREENVILLE CREEK. Samples collected in 1900.					
Greenville, above town.....	April 17	.20	.08	Slight	Faint vegetative
“ “ “.....	May 22	.28	.07	“	Vegetative
“ “ “.....	June 18	.25	.08	“	“
“ “ “.....	July 10	.27	.18	“	“
“ “ “.....	Aug. 7	.22	.17	Considerable	“
“ “ “.....	Sept. 3	.23	.14	Slight	“
“ “ “.....	Oct. 1	.42	.30	Considerable	“
“ “ “.....	Nov. 1	.20	.08	Slight	Earthy
Average.....		.26	.14		
Greenville, below town.....	April 17	.25	.18	Slight	Sour
“ “ “.....	May 22	.25	.11	“	Vegetative
“ “ “.....	June 18	.23	.10	Considerable	“
“ “ “.....	July 10	.23	.16	Slight	Faint musty
“ “ “.....	Aug. 7	.23	.23	Considerable	Vegetative
“ “ “.....	Sept. 3	.21	.17	Slight	Vegetative and faint musty
“ “ “.....	Oct. 1	.48	.38	Considerable	Vegetative
“ “ “.....	Nov. 1	.30	.08	Slight	Earthy
Average.....		.27	.18		
Dayton ² above town.....	April 18	.26	.40	Considerable	Earthy
“ “ “.....	May 23	.14	.08	Slight	Faint vegetative
“ “ “.....	June 19	.28	.15	Considerable	Faint sour
“ “ “.....	July 10	.25	.16	Very slight	Vegetative
“ “ “.....	Aug. 8	.25	.13	Slight	“
“ “ “.....	Sept. 4	.25	.25	“	Sour
“ “ “.....	Oct. 2	.21	.19	“	Faint vegetative
“ “ “.....	Nov. 2	.24	.27	“	“ “
Average.....		.23	.20		

¹Turbidity in terms of silica standard.²This series of samples was taken on the Stillwater River. The State Board of Health looked upon the two sets of samples from Greenville Creek and this one from the Stillwater River as representative of the Stillwater Basin.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
7.1	35.6	106.	35.	141.	745
0.6	12.9	88.	None	88.	220
0.8	147.7	98.	.....	98.	553
Trace	12.1	86.	.....	86.	154
2.1	52.1	94.	.....	94.	418
6.2	53.8	101.	76.	177.	608
0.4	18.1	88.	16.	104.	234
Trace	35.4	96.	.....	96.	263
"	10.5	85.	.....	85.0	159
1.6	29.5	92.	.....	92.	316
15.0	0.2	217.8	83.0	300.8	449
9.3	Trace	226.2	40.0	266.2	380
2.4	0.6	278.4	31.0	309.4	467
2.0	0.4	280.0	None	280.0	369
None	2.7	255.4	3.2	258.6	421
Trace	1.0	269.0	None	269.0	413
9.3	None	189.6	35.0	224.6	432
Trace	1.5	274.0	26.6	300.6	472
4.9	0.8	248.8	27.3	276.1	425
14.2	0.8	214.2	74.4	288.6	474
10.6	1.0	235.8	55.2	291.0	422
2.4	2.0	268.4	55.0	323.4	535
3.2	3.0	285.2	8.2	293.4	415
0.7	5.0	270.6	None	270.6	483
0.2	3.9	265.0	9.4	274.4	484
10.6	1.0	194.6	3.8	198.4	521
None	3.9	280.0	42.6	322.6	464
5.3	2.6	251.7	35.4	287.1	475
16.8	0.4	187.8	24.0	211.8	478
3.6	1.1	218.2	None	218.2	348
10.2	1.0	244.0	21.	265.0	434
4.3	0.1	229.2	13.2	242.4	361
None	0.8	223.2	3.2	226.4	342
2.6	0.3	221.4	5.2	226.6	376
0.1	2.3	231.4	None	231.4	381
34.1	1.3	196.0	None	196.0	317
8.9	0.9	218.9	8.3	227.2	380

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
KILLBUCK CREEK. Samples collected in 1899.					
Wooster, above town.....	May 4	.18	.28	Slight	Faint earthy
" " "	May 30	.35	.15	"	None
" " "	June 28	.20	.40	"	Earthy
" " "	July 19	.22	.65	Considerable	Faint musty
" " "	Aug. 18	.50	.33	Slight	" "
" " "	Sept. 19	.20	.68	Considerable	" "
" " "	Oct. 12	.25	.26	"	Musty
" " "	Nov. 16	.40	.32	Slight	Earthy
Average.....		.29	.38		
Wooster, below town.....	May 4	.20	.19	Slight	Faint musty
" " "	May 30	.38	1.10	Considerable	Earthy
" " "	June 28	.20	.35	"	Musty
" " "	July 19	.22	.45	"	"
" " "	Aug. 18	.40	.32	Slight	"
" " "	Sept. 19	.25	.65	Considerable	"
" " "	Oct. 12	.25	.23	"	"
" " "	Nov. 16	.35	.19	Slight	Earthy
Average.....		.28	.43		
KOKOSING RIVER. Samples collected in 1899.					
Mt. Vernon, above town.....	May 3	.05	.04	Slight	None
" " " "	May 29	.25	.21	Considerable	Earthy
" " " "	June 27	.10	.08 ¹	Very slight	None
" " " "	July 18	.28	.32	Slight	Faint musty
" " " "	Aug. 17	.10	.05 ¹	Very slight	None
" " " "	Sept. 18	.10	.05 ¹	" "	"
" " " "	Oct. 16	.05	.05 ¹	" "	Faint musty
" " " "	Nov. 21	.12	.05 ¹	Trace	None
Average.....		.13	.11		
Mt. Vernon, below town.....	May 3	.10	.06 ¹	Slight	None
" " " "	May 29	.30	.52	Considerable	Faint musty
" " " "	June 27	.12	.10	Very slight	" "
" " " "	July 18	.25	.23	Considerable	Musty
" " " "	Aug. 17	.10	.07 ¹	Very slight	Faint musty
" " " "	Sept. 18	.10	.07 ¹	" "	" "
" " " "	Oct. 16	.05	.07 ¹	" "	None
" " " "	Nov. 21	.12	.06 ¹	Trace	"
Average.....		.14	.15		

¹Turbidity rod on bottom of stream with wire still visible.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.2	1.9	112.4	3.5	115.9	214
0.7	1.6	116.4	19.8	136.2	194
Trace	6.4	148.2	.....	148.2	331
0.2	10.2	124.2	6.8	131.0	377
0.1	5.5	125.2	49.2	174.4	336
0.2	4.6	127.4	6.2	133.6	413
0.2	4.4	148.	12.6	160.6	352
0.1	8.3	139.2	88.8	228.0	471
0.2	5.4	130.1	23.4	153.5	336
0.3	3.9	121.4	7.4	128.8	258
1.6	4.2	93.9	9.3	103.2	439
0.5	7.3	146.4	.....	146.4	327
0.3	8.9	127.6	5.6	133.2	338
0.0	7.6	130.8	47.8	178.6	323
0.1	4.8	130.2	38.4	168.6	419
0.1	7.8	155.8	34.6	190.4	343
0.2	7.5	138.0	83.0	221.0	423
0.4	6.5	130.5	28.3	158.8	359
0.1	0.6	174.0	11.1	185.1	295
0.4	0.8	175.1	.....	175.1	310
0.1	1.4	194.5	.....	194.5	266
0.1	0.8	148.8	27.4	176.2	264
.....	3.5	206.6	9.6	216.2	247
0.3	0.6	209.2	11.6	220.8	288
0.2	0.7	220.4	23.8	244.2	309
0.8	0.9	207.8	27.8	235.6	278
0.2	1.2	192.0	13.9	205.9	282
0.1	3.9	173.2	69.1	242.3	273
0.4	1.4	168.7	.....	168.7	393
0.5	3.7	189.2	.....	189.2	287
0.1	2.2	152.6	47.8	200.4	272
0.1	4.5	206.2	13.0	219.2	315
0.3	3.7	211.8	35.8	247.6	302
0.2	2.9	220.0	73.4	295.4	305
0.9	2.3	203.6	27.4	231.0	280
0.4	3.1	190.7	33.3	224.0	303

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
LICKING RIVER. Samples collected in 1899.					
Newark, above town.....	May 3	.05	.04 ¹	Very slight	None
" " "	May 25	.10	.03 ¹	" "	"
" " "	June 23	.28	.65	Considerable	Earthy
" " "	July 27	.25	.57	Considerable	Vegetative
" " "	Aug. 31	.10	.03 ¹	Very slight	None
" " "	Sept. 28	.07	.03 ¹	Trace	"
" " "	Oct. 10	.05	.03 ¹	"	"
" " "	Nov. 14	.12	.04 ¹	"	"
Average.....		.13	.18		
Newark, below town.....	May 3	.05	.05 ¹	Very slight	None
" " "	May 25	.13	.06 ¹	" "	Musty
" " "	June 23	.30	.78	Considerable	Earthy
" " "	July 27	.25	.52	"	Sour musty
" " "	Aug. 31	.10	.06 ¹	Very slight	Musty
" " "	Sept. 28	.10	.03	Trace	None
" " "	Oct. 10	.05	.03	"	"
" " "	Nov. 14	.12	.03	Very slight	"
Average.....		.14	.20		
Zanesville, above town.....	May 23	.12	.07	Slight	Faint earthy
" " "	June 21	.20	3.25	Considerable	Earthy
" " "	July 27	.25	1.00	"	"
" " "	Aug. 31	.15	.18	Slight	Vegetative
" " "	Sept. 28	.10	.18	"	None
" " "	Oct. 18	.12	.14	Considerable	"
" " "	Nov. 23	.10	.08	Very slight	"
Average.....		.15	.70		
Zanesville, Ice Field.....	April 29	.10	.11	Slight	None
" " "	May 23	.18	.08	"	Faint earthy
" " "	June 21	.20	3.25	Considerable	Earthy
" " "	July 27	.25	.95	"	"
" " "	Aug. 31	.15	.17	Slight	Vegetative
" " "	Sept. 28	.12	.15	"	None
" " "	Oct. 18	.12	.16	Considerable	"
" " "	Nov. 23	.10	.08	Very slight	"
Average.....		.15	.62		
MAD RIVER. Samples collected in 1900.					
Urbana, above town.....	April 19	.32	.25	Considerable	Earthy
" " "	May 24	.12	.05	Slight	Faint earthy
" " "	June 20	.21	.18	Considerable	Faint vegetative
" " "	July 9	.18	.25	Slight	" "

¹Turbidity rod on bottom of stream with wire still visible.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.1	1.4	165.5	43.8	209.3	300
0.3	1.3	184.6	None	184.6	288
0.3	0.8	155.0	17.8	172.8	367
0.2	1.2	145.8	None	145.8	392
None	0.9	159.0	55.2	214.2	289
0.3	2.8	212.2	6.0	218.2	277
None	2.8	213.0	27.2	240.2	279
0.1	1.7	201.0	20.2	221.2	278
0.2	1.6	184.0	21.3	205.3	309
0.1	2.8	139.4	21.6	161.0	316
0.4	1.6	179.3	None	179.3	285
0.7	1.0	86.2	12.6	98.8	306
0.3	3.5	143.6	None	143.6	416
0.3	4.7	230.0	18.8	248.8	335
0.4	4.2	224.0	None	224.0	331
0.2	3.7	229.4	28.8	258.2	333
0.2	2.4	219.0	25.4	244.4	308
0.3	3.0	181.4	13.4	194.8	329
0.3	3.9	179.7	19.6	199.3	299
0.2	2.0	84.4	32.8	117.2	1606
0.2	1.6	108.2	19.6	127.8	416
0.0	4.9	192.6	6.4	199.0	319
0.4	4.1	199.6	1.8	201.4	299
Trace	2.9	193.6	35.2	228.8	339
0.4	3.1	199.0	34.2	233.2	295
0.2	3.2	165.3	21.4	186.7	510
0.5	3.1	135.9	2.4	138.3	279
0.2	3.7	171.1	12.6	183.7	286
0.3	1.2	65.6	49.0	114.6	1083
0.3	1.4	88.6	8.2	96.8	434
0.3	5.0	217.6	8.8	226.4	308
0.3	4.1	196.6	32.8	229.4	311
None	3.0	208.2	20.0	228.2	358
0.5	3.4	192.6	19.8	212.4	296
0.3	3.1	159.5	19.2	178.7	419
8.4	Trace	229.0	60.6	289.6	497
3.6	0.5	265.4	3.0	268.4	347
3.7	Trace	271.8	26.8	298.6	434
2.8	0.2	266.2	11.4	277.6	410

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
MAD RIVER—Concluded.					
Urbana, above town.....	Aug. 9	.22	.24	Slight	Vegetative
“ “ “.....	Sept. 5	.28	.38	Considerable	Earthy, vegetative
“ “ “.....	Oct. 3	.18	.23	Slight	Vegetative
“ “ “.....	Nov. 3	.20	.08	Very slight	None
Average.....		.21	.21		
Urbana, below town.....	April 19	.35	.25	Considerable	Strong
“ “ “.....	May 24	.58	.19	“	Strawboard
“ “ “.....	June 20	.60	.35	“	“
“ “ “.....	July 9	.22	.30	“	Vegetative
“ “ “.....	Aug. 9	.52	.20	“	Foul
“ “ “.....	Sept. 5	.55	.42	“	Strawboard
“ “ “.....	Oct. 3	.55	.27	“	“
“ “ “.....	Nov. 3	.40	.25	Much	“
Average.....		.47	.28		
Springfield, above town.....	April 16	.20	.07	Slight	Earthy
“ “ “.....	May 24	.27	.12	Considerable	Vegetative
“ “ “.....	June 20	.25	.20	“	Earthy
“ “ “.....	July 10	.22	.30	Slight	Sweet, vegetative
“ “ “.....	Aug. 9	.35	.19	Considerable	Vegetative
“ “ “.....	Sept. 5	.23	.36	“	“
“ “ “.....	Oct. 3	.29	.27	“	“
“ “ “.....	Nov. 3	.38	.15	“	“
Average.....		.27	.21		
Springfield, below town.....	April 16	.20	.07	Slight	Faint musty
“ “ “.....	May 24	.27	.13	Considerable	Musty
“ “ “.....	June 20	.25	.24	“	Faint musty
“ “ “.....	July 10	.20	.24	“	“ “
“ “ “.....	Aug. 9	.28	.17	“	Musty
“ “ “.....	Sept. 5	.21	.32	Slight	Vegetative
“ “ “.....	Oct. 3	.21	.21	Considerable	Faint musty
“ “ “.....	Nov. 3	.32	.13	“	“ “
Average.....		.24	.19		
Dayton, above town.....	April 18	.20	.28	Considerable	Earthy
“ “ “.....	May 23	.12	.13	Slight	“
“ “ “.....	June 19	.22	.27	Considerable	Faint earthy
“ “ “.....	July 10	.20	.14	Very slight	Faint sour
“ “ “.....	Aug. 8	.20	.23	Slight	Earthy
“ “ “.....	Sept. 4	.23	.23	Considerable	Vegetative
“ “ “.....	Oct. 2	.23	.19	Slight	Earthy
“ “ “.....	Nov. 2	.19	.16	“	“
Average.....		.20	.20		

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
4.4	0.2	250.4	None	250.4	396
3.7	Trace	230.4	21.0	251.4	438
5.8	1.0	260.2	1.6	261.8	462
Trace	Trace	251.4	1.4	252.8	390
4.0	0.2	253.1	14.5	267.6	422
12.4	0.4	225.0	43.4	268.4	466
Trace	0.7	285.2	24.0	309.2	396
None	0.2	305.6	36.2	341.8	485
2.7	0.6	282.8	17.0	299.8	399
Trace	6.4	284.6	11.6	296.2	463
0.7	0.3	266.6	None	266.6	481
0.3	0.6	283.8	None	283.8	493
0.5	0.5	295.8	None	295.8	462
2.1	1.2	278.7	16.5	295.2	456
4.9	0.5	261.0	11.8	272.8	412
0.4	0.2	276.2	5.6	281.8	426
2.0	0.7	278.6	40.4	319.0	423
4.4	0.9	268.2	None	268.2	462
None	0.4	288.2	None	288.2	430
4.9	0.8	248.4	39.	287.4	430
0.4	0.2	274.8	None	274.8	456
0.2	0.5	281.4	None	281.4	410
2.1	0.5	272.1	12.1	284.2	431
6.6	1.7	256.2	22.2	278.4	427
1.2	2.4	274.8	25.2	300.0	404
2.6	3.6	279.6	3.2	282.8	484
3.8	3.5	267.2	13.8	281.0	459
1.2	4.5	273.4	None	273.4	405
5.8	4.5	260.0	9.4	269.4	427
0.2	3.1	272.2	None	272.2	473
0.2	3.3	281.4	None	281.4	401
2.7	3.3	270.6	9.2	279.8	435
9.3	1.5	241.6	12.8	254.4	535
3.5	3.0	259.8	32.2	292.0	368
1.7	3.1	266.0	37.0	303.0	460
2.7	4.0	259.2	None	259.2	408
3.0	2.5	243.2	None	243.2	425
4.0	2.6	257.8	None	257.8	451
3.4	2.9	250.2	None	250.2	406
19.5	2.7	261.0	2.98	263.98	385
5.8	2.8	254.8	14.0	268.8	417

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
MAHONING RIVER. Samples collected in 1897.					
Alliance, above Pat. St. Br....	June 19	.45	None	Marked	Slight earthy
" " " ...	July 24	.7	Slight	"	Faint "
" " " ...	Sept. 2	.4	Distinct	"	Slight musty
" " " ...	Sept. 29	.15	None	Slight	" earthy
" " " ...	Oct. 27	.2	Very slight	Distinct	" "
" " " ...	Nov. 26	1.0	Turbid	Marked	None
Average.....					
Alliance, below Pat. St. Br....	June 19	.3	None	Distinct	Slight earthy
" " " ...	July 24	.8	Slight	Marked	Earthy
" " " ...	Sept. 2	.3	"	"	Slight musty
" " " ...	Sept. 29	.2	None	Slight	Sour musty
" " " ...	Oct. 27	.4	"	Marked	Slight offensive
" " " ...	Nov. 26	.5	Very marked	Distinct	Faint musty
Average.....					
Warren, above town.....	June 18	.3	None	Marked	Faint musty
" " "	July 23	1.2	Very marked	Very marked	" "
" " "	Aug. 28	.3	Very slight	Slight	Slight earthy
" " "	Sept. 30	.15	Trace	"	" "
" " "	Oct. 28	.3	Slight	"	Earthy
" " "	Nov. 27	.7	Very marked	Distinct	None
Average.....					
Warren, below town.....	June 18	.35	None	Distinct	Faint musty
" " "	July 23	1.2	Very marked	Very marked	" "
" " "	Aug. 28	.3	Slight	Distinct	" "
" " "	Sept. 30	.2	None	Slight	Musty
" " "	Oct. 28	.3	Slight	"	Slight offensive
" " "	Nov. 27	1.0	Very marked	Marked	Faint musty
Average.....					
Niles.....	July 24	1.0	Marked	Marked	Sour earthy
"	Aug. 28	.35	Very slight	Very slight	None
"	Sept. 30	.15	" "	Slight	Slight musty
"	Oct. 28	.30	Slight	"	" earthy
"	Nov. 27	.8	Marked	Marked	Musty
Average.....					
Girard, above town.....	June 18	.6	None	Distinct	Slight musty
Youngstown, above town....	June 18	.5	None	Slight	Musty
" " "	July 23	2.5	Very turbid	Heavy	Slight musty
" " "	Aug. 28	...	Trace	Marked	" "
" " "	Sept. 30	.15	None	Slight	Musty
" " "	Oct. 28	.3	"	Distinct	Slight musty
" " "	Nov. 27	2.0	Turbid	Marked	Faint sweetish
Average.....					

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
1.0	1.5	110.	36.	146.	240
1.2	0.2	70.	38.	108.	175
0.3	2.3	136.	54.	190.	400
0.0	3.0	182.	58.	240.	415
Trace	3.2	204.	54.	258.	410
28.8	2.3	78.	64.	142.	470
0.9	2.1	130.	51.	181.	350
0.3	3.0	128.	56.	184.	300
1.5	0.2	56.	34.	90.	165
0.5	4.8	138.	68.	206.	410
Trace	9.0	170.	68.	238.	415
0.1	15.5	216.	98.	314.	480
2.4	4.5	102.	98.	200.	380
0.8	6.2	135.	70.	205.	358
0.4	2.0	92.	16.	108.	190
1.0	0.3	36.	22.	58.	130
Trace	3.5	100.	28.	128.	245
0.0	4.2	124.	32.	156.	275
0.0	3.7	140.	14.	154.	235
3.8	3.3	54.	46.	100.	205
0.9	2.8	91.	26.	117.	213
0.2	4.0	102.	24.	126.	200
1.1	0.3	34.	18.	52.	135
0.0	4.5	100.	26.	126.	255
None	4.5	124.	12.	136.	245
0.3	6.2	140.	3.	143.	250
3.9	3.3	54.	42.	96.	233
0.9	3.8	92.	21.	113.	220
1.2	2.1	40.	36.	76.	170
0.3	4.5	90.	26.	116.	235
None	8.7	126.	18.	144.	275
0.5	42.5	138.	30.	168.	335
3.8	5.0	56.	56.	112.	270
1.2	12.6	90.	33.	123.	257
0.2	5.8	76.	32.	108.	200
0.2	5.3	90.	28.	118.	245
0.8	0.3	22.	20.	42.	145
0.3	4.0	56.	24.	80.	200
Trace	13.5	88.	86.	174.	370
0.2	15.2	106.	66.	172.	380
2.0	5.0	64.	54.	118.	255
0.5	7.2	71.	46.	117.	266

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
MAHONING RIVER—Concluded.					
Haselton Bridge.....	June 18	.4	None	Slight	Sour musty
“ “	July 23	2.5	Very turbid	Heavy	Slight earthy
“ “	Aug. 28	.85	Trace	Marked	“ sweetish
“ “	Sept. 30	.2	None	Slight	Sour musty
“ “	Oct. 28	.5	Slight	Distinct	Offensive
“ “	Nov. 27	2.0	Turbid	Very marked	Musty
Average.....					
MAHONING RIVER, SPECIAL ANALYSES. Samples collected in 1897.					
Warren, filtered water.....	June 18	.35	None	Slight	Faint musty
“ “ “	July 23	.1	“	None	“ “
“ “ “	Aug. 28	.2	“	“	Slight earthy
“ “ “	Oct. 29	.15	“	“	Earthy
“ “ “	Nov. 27	.10	“	“	None
Average.....					
Alliance, Sewage.....	June 19	.3	Slight	Very marked	Offensive
“ “	July 24	.3	None	Marked	“
“ “	Sept. 2	.2	Slight	“	Oily and slight offensive
“ “	Oct. 2	.3	Distinct	“	Slight offensive
“ “	Oct. 29	.25	Trace	“	Oily
Average.....					
Alliance, Effluent.....	June 19	.25	Slight	Slight	Earthy
“ “	July 24	.2	None	Marked	Faint musty
“ “	Sept. 2	.2	Very slight	“	Slight greasy and musty
“ “	Oct. 2	.25	Slight	Slight	Faint musty
“ “	Oct. 29	.25	Very slight	“	Musty
Average.....					
MAUMEE RIVER. Samples collected in 1898.					
Ft. Wayne, below town.....	July 22	.2	Slight	Slight	Foul
“ “ “ “	Aug. 23	.3	“	“	Sewage
“ “ “ “	Sept. 27	.4	“	Considerable	“
“ “ “ “	Oct. 25	.6	Distinct	Slight	Faint sour
“ “ “ “	Nov. 16	.38	Decided	Considerable	Peculiar earthy
Average.....		.33			
Defiance, above town.....	July 22	.1	Very slight	Very slight	None
“ “ “ “	Aug. 24	.25	“ “	“ “	“
“ “ “ “	Sept. 27	.4	Slight	Slight	“
“ “ “ “	Oct. 25	.42	Very slight	“	Faint woody
“ “ “ “	Nov. 15	.35	Decided	Considerable	Earthy
Average.....		.3			

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.4	7.0	96.	28.	124.	225
1.4	0.5	26.	38.	64.	200
1.2	6.5	64.	28.	92.	215
0.8	18.0	114.	70.	184.	390
1.2	25.2	130.	78.	208.	405
2.5	5.7	52.	58.	110.	283
1.2	10.5	80.	50.	130.	286
0.3	2.0	94.	24.	118.	175
1.3	0.7	10.	42.	52.	105
Trace	3.0	100.	28.	128.	245
0.0	4.0	142.	26.	168.	245
4.1	2.4	22.	58.	80.	155
1.2	2.4	74.	36.	110.	185
None	30.0	212.	.....	.....	490
2.0	25.5	158.	128.	286.	475
2.7	16.5	178.	94.	272.	490
None	18.5	200.	94.	294.	525
0.4	15.0	186.	100.	286.	490
1.0	21.1	187.	104.	291.	494
None	21.0	146.	120.	266.	395
1.6	32.5	134.	140.	274.	490
2.4	22.3	178.	110.	288.	480
None	19.0	150.	84.	234.	440
"	17.0	142.	102.	244.	420
0.8	22.3	150.	111.	261.	445
1.4	139.0	229.0	101.2	330.2	507
0.7	45.2	191.8	41.8	233.6	475
1.6	20.9	219.0	38.8	257.8	421
1.9	31.8	170.2	55.0	225.2	470
38.9	15.5	123.2	22.4	145.6	373
8.9	50.5	186.6	51.8	238.4	449
1.8	24.5	157.2	69.0	226.2	415
0.8	14.9	144.6	4.2	148.8	364
0.8	17.7	174.3	12.1	186.4	441
1.6	25.2	150.6	45.0	195.6	498
47.4	13.6	113.3	41.0	154.3	393
10.6	19.2	148.0	34.3	182.3	422

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
MAUMEE RIVER—Concluded.					
Defiance, below town.....	July 22	.2	Distinct	Slight	Faint offensive
“ “ “	Aug. 24	.35	Slight	“	Slight musty
“ “ “	Sept. 27	.5	“	“	Musty
“ “ “	Oct. 25	.4	“	“	Earthy
“ “ “	Nov. 15	.32	Decided	Considerable	“
Average.....		.35			
Napoleon, above town.....	July 23	.2	Distinct	Very slight	None
“ “ “	Aug. 25	.3	Slight	“ “	“
“ “ “	Sept. 28	.35	“	Slight	“
“ “ “	Oct. 26	.4	Distinct	“	Earthy
“ “ “	Nov. 15	.32	Decided	Considerable	“
Average.....		.31			
Napoleon, below town.....	July 23	.2	Distinct	Slight	Slight sour
“ “ “	Aug. 25	.33	Slight	Very slight	None
“ “ “	Sept. 28	.35	“	Slight	Faint musty
“ “ “	Oct. 26	.4	Distinct	“	“ “
“ “ “	Nov. 15	.32	Decided	Considerable	Earthy
Average.....		.32			
Toledo, above town.....	July 23	.1	Distinct	Slight	None
“ “ “	Aug. 25	.25	Very slight	Very slight	“
“ “ “	Sept. 27	.4	“ “	Slight	“
“ “ “	Oct. 26	.42	Distinct	“	Faint musty
“ “ “	Nov. 14	.3	Decided	Considerable	Earthy
Average.....		.29			
Toledo, Cherry St. Bridge....	July 23	.1	Distinct	Slight	Offensive
“ “ “	Aug. 25	.28	Very slight	“	Musty
“ “ “	Sept. 27	.42	“ “	“	Faint sour
“ “ “	Oct. 26	.4	Distinct	“	Musty
“ “ “	Nov. 14	.3	Decided	Considerable	Earthy
Average.....		.30			
Toledo, Riverside Park.....	July 23	.1	Distinct	Slight	Offensive
“ “ “	Aug. 25	.3	Very slight	“	Musty
“ “ “	Sept. 27	.45	“ “	“	Faint sour
“ “ “	Oct. 26	.4	Distinct	“	Musty
“ “ “	Nov. 14	.3	Decided	Considerable	Earthy, faint oily
Average.....		.31			

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
1.8	42.1	160.4	75.8	236.2	620
1.3	51.7	150.2	12.6	162.8	431
0.9	30.3	173.8	None	173.8	381
4.9	77.2	159.6	40.4	200.0	568
42.9	26.7	140.7	38.8	179.5	410
10.2	46.5	156.9	33.5	190.4	482
2.0	29.5	146.8	20.0	166.8	390
1.4	64.3	137.2	31.2	168.4	439
1.0	104.6	144.6	12.2	156.8	486
1.2	36.1	156.4	41.0	197.4	399
45.6	8.1	118.2	24.2	142.4	395
10.2	48.5	140.6	25.7	166.3	422
1.9	32.7	152.6	47.3	199.9	436
1.6	66.0	139.8	14.8	154.6	480
1.1	81.1	153.8	32.0	185.8	573
1.3	37.2	168.2	43.6	211.8	474
44.3	12.2	112.8	26.6	139.4	421
10.2	45.8	145.4	32.9	178.3	477
1.1	29.2	156.6	40.2	196.8	365
1.2	50.2	150.2	5.0	155.2	434
0.6	60.2	154.9	20.4	175.3	515
0.7	34.4	142.4	31.0	173.4	462
36.7	21.1	122.4	13.6	136.0	439
8.0	39.0	145.3	22.0	167.3	443
1.6	29.4	164.2	65.8	230.0	372
1.5	44.5	143.6	9.2	152.8	481
0.6	63.6	161.5	19.5	181.0	491
1.5	63.8	141.6	32.8	174.4	456
35.9	32.3	130.2	28.0	158.2	432
8.4	46.7	148.2	31.1	179.3	446
1.6	26.6	157.0	46.1	203.1	338
1.3	40.6	148.4	18.0	166.4	502
0.6	63.3	158.8	23.6	182.4	449
1.2	64.3	140.0	30.6	170.6	524
38.1	28.1	128.4	32.0	160.4	473
8.4	44.6	146.5	30.1	176.6	457

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
MIAMI RIVER. Samples collected in 1900.					
Sidney, above town.....	April 17	.20	.11	Slight	Vegetative
“ “ “	May 22	.20	.16	“	“
“ “ “	June 18	.22	.15	“	“
“ “ “	July 9	.22	.20	“	“
“ “ “	Aug. 7	.30	.12	“	“
“ “ “	Sept. 3	.26	.22	“	“
“ “ “	Oct. 1	.24	.14	“	Faint vegetative
“ “ “	Nov. 1	.22	.22	“	Vegetative
Average.....		.23	.16		
Sidney, below town.....	April 17	.20	.11	Slight	Vegetative
“ “ “	May 22	.22	.09	“	“
“ “ “	June 18	.28	.10	“	“
“ “ “	July 9	.20	.14	“	“
“ “ “	Aug. 7	.30	.09	“	“
“ “ “	Sept. 3	.27	.15	“	“
“ “ “	Oct. 1	.25	.17	“	“
“ “ “	Nov. 1	.20	.13	“	“
Average.....		.24	.12		
Piqua, above town.....	April 18	.35	3.00	Much	Earthy
“ “ “	May 22	.30	.17	Considerable	Vegetative
“ “ “	June 18	.25	.33	“	Earthy
“ “ “	July 11	.27	.15	Slight	Vegetative
“ “ “	Aug. 7	.25	.12	“	Faint musty
“ “ “	Sept. 3	.25	.18	“	Vegetative
“ “ “	Oct. 1	.30	.40	Considerable	“
“ “ “	Nov. 1	.28	.26	Slight	Earthy
Average.....		.28	.58		
Piqua, below town.....	April 18	.22	2.70	Much	Earthy
“ “ “	May 22	.30	.11	Slight	Faint musty
“ “ “	June 18	.27	.26	Considerable	“ “ and earthy
“ “ “	July 11	.28	.14	Slight	Sour
“ “ “	Aug. 7	.28	.17	“	Musty
“ “ “	Sept. 3	.26	.15	“	Vegetative and faint musty
“ “ “	Oct. 1	.30	.30	Considerable	Musty
“ “ “	Nov. 1	.24	.24	Slight	Faint musty
Average.....		.27	.51		
Troy, above town.....	April 17	.20	.12	Slight	Faint sour
“ “ “	May 23	.20	.08	“	Faint musty
“ “ “	June 19	.27	.13	“	“ “
“ “ “	July 11	.30	.18	“	Musty

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
15.9	0.4	194.2	52.8	247.0	408
1.6	1.7	230.2	33.0	263.2	381
None	0.4	237.0	35.0	202.0	414
0.8	1.6	221.2	68.4	289.6	457
None	0.4	212.2	1.0	213.2	350
0.1	0.2	220.4	56.0	276.4	406
None	0.4	221.0	None	221.0	393
Trace	0.6	222.0	20.4	242.4	422
2.3	0.7	219.8	33.3	253.1	404
13.3	0.6	205.8	42.0	247.8	430
2.6	2.6	226.8	13.0	239.8	345
0.4	3.8	252.6	54.0	306.6	402
2.5	2.7	231.2	30.4	261.6	360
None	3.4	219.8	5.4	225.2	352
1.4	1.9	223.6	25.8	249.4	374
None	0.9	199.0	None	199.0	364
Trace	2.5	232.6	36.8	269.4	409
2.5	2.3	223.9	25.9	249.8	379
19.5	Trace	118.6	38.8	157.4	1123
1.5	1.9	225.8	41.8	267.6	367
0.8	0.8	239.0	50.0	289.0	463
Trace	1.4	219.2	32.4	251.6	426
None	1.6	205.2	15.2	220.4	370
1.2	0.6	206.4	29.0	235.4	355
None	0.7	170.2	8.8	179.0	353
Trace	2.2	220.2	39.0	259.2	414
2.9	1.2	200.6	31.9	232.5	484
22.1	Trace	137.4	19.0	156.4	853
3.3	4.1	228.2	31.8	260.0	364
1.4	1.6	241.0	36.0	277.0	493
2.2	4.8	226.2	47.4	273.6	499
None	5.1	223.8	22.0	245.8	384
3.0	4.8	216.0	15.8	231.8	387
Trace	2.5	178.2	3.2	181.4	371
None	4.0	220.4	25.0	245.4	394
4.0	3.4	208.9	25.0	233.9	468
11.5	1.9	187.0	53.8	240.8	407
0.9	2.6	228.0	17.0	245.0	352
2.1	1.6	237.2	55.0	292.2	423
2.0	2.5	222.4	47.4	269.8	465

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
MIAMI RIVER—Continued.					
Troy, above town.....	Aug. 8	.34	.10	Slight	Faint musty
“ “ “	Sept. 4	.28	.15	“	“ “
“ “ “	Oct. 2	.27	.15	“	“ “
“ “ “	Nov. 2	.25	.21	“	“ “
Average.....		.26	.14		
Troy, below town.....	April 17	.18	.14	Slight	Faint sour
“ “ “	May 23	.16	.08	“	Faint musty
“ “ “	June 19	.27	.06	“	Musty
“ “ “	July 11	.28	.12	“	Faint musty
“ “ “	Aug. 8	.20	.06	“	“ “
“ “ “	Sept. 4	.29	.11	“	“ “
“ “ “	Oct. 2	.25	.08	Very slight	“ “
“ “ “	Nov. 2	.26	.13	Slight	“ “
Average.....		.24	.10		
Dayton, above town.....	April 18	.25	.21	Considerable	Earthy
“ “ “	May 23	.22	.19	Slight	Faint musty
“ “ “	June 19	.30	.30	Considerable	Vegetative
“ “ “	July 10	.25	.19	Slight	Vegetative, earthy
“ “ “	Aug. 8	.26	.20	“	Earthy
“ “ “	Sept. 4	.30	.33	Considerable	Vegetative
“ “ “	Oct. 2	.21	.26	“	Faint musty
“ “ “	Nov. 2	.19	.29	Slight	Earthy
Average.....		.25	.25		
Dayton, below town.....	April 18	.28	.60	Considerable	Faint musty
“ “ “	May 23	.26	.13	“	“ “
“ “ “	June 19	.23	.11	“	Earthy
“ “ “	July 10	.25	.15	Slight	Musty
“ “ “	Aug. 8	.24	.16	“	“
“ “ “	Sept. 4	.26	.20	“	Musty, oily
“ “ “	Oct. 2	.25	.16	“	Musty
“ “ “	Nov. 2	.22	.18	“	Faint musty
Average.....		.25	.21		
Middletown, above town.....	April 26	.22	.09	Considerable	Strong vegetative
“ “ “	May 28	.31	.14	Slight	Vegetative
“ “ “	June 28	.35	1.90	Much	“
“ “ “	July 19	.26	.57	Considerable	Faint musty
“ “ “	Aug. 22	.26	.67	“	Earthy, vegetative
“ “ “	Sept. 19	.18	.13	Very slight	Vegetative
“ “ “	Oct. 13	.38	.35	Considerable	“
“ “ “	Nov. 7	.23	.12	Slight	“
Average.....		.27	.50		

SURFACE WATERS OF OHIO—Continued

Nitrate ion (NO ₃)	Chloride ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
Trace	2.3	215.8	4.2	220.0	337
2.4	2.5	207.4	10.2	217.6	377
0.1	2.3	195.4	22.8	218.2	353
Trace	3.4	224.4	7.4	231.8	389
2.4	2.4	214.7	27.2	241.9	388
15.0	1.4	184.8	56.6	241.4	379
2.0	5.0	240.4	40.0	280.4	347
0.5	2.6	247.8	17.6	265.4	383
1.6	3.7	231.2	13.0	244.2	438
1.0	3.0	224.8	None	224.8	312
1.5	2.8	213.2	29.2	242.4	342
Trace	3.4	210.4	None	210.4	338
Trace	3.4	222.6	7.0	229.6	377
2.7	3.2	221.9	20.4	242.3	364
16.4	0.6	189.2	10.2	199.4	448
4.4	1.4	239.6	44.2	283.8	366
2.1	1.8	237.0	23.0	260.0	445
0.9	1.8	224.4	70.8	295.2	442
None	1.2	219.4	30.6	250.0	368
Trace	1.0	222.0	None	222.0	388
0.2	2.3	224.0	None	224.0	403
Trace	1.8	212.0	20.2	232.2	400
3.0	1.5	220.9	24.9	245.8	407
16.0	0.8	193.4	67.2	260.6	591
4.9	3.9	240.2	8.2	248.4	351
1.8	4.7	245.0	47.0	292.0	436
5.3	5.5	237.2	4.0	241.2	352
1.5	4.4	230.2	None	230.2	400
3.0	3.9	225.6	33.0	258.6	398
0.2	3.8	223.8	15.0	238.8	349
38.9	6.9	227.0	14.0	241.0	380
8.9	4.2	227.8	23.5	251.3	407
11.5	1.6	204.2	6.0	210.2	373
2.5	4.4	237.0	None	237.0	406
0.5	0.6	194.8	12.4	207.2	556
1.4	4.0	211.0	54.6	265.6	453
Trace	2.4	204.8	40.8	245.6	403
Trace	6.1	230.2	18.0	248.2	422
None	3.3	189.0	None	189.0	410
0.2	4.1	226.4	16.0	242.4	363
2.0	3.3	212.2	18.5	230.7	423

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
MIAMI RIVER—Concluded.					
Middletown, below town.	April 26	.24	.21	Considerable	Vegetative
“ “ “	May 28	.31	.16	Slight	Faint musty
“ “ “	June 28	.35	1.80	Much	Oily
“ “ “	July 19	.26	.54	Considerable	Musty
“ “ “	Aug. 22	.30	.73	“	Earthy
“ “ “	Sept. 19	.28	.30	Slight	Vegetative, faint musty
“ “ “	Oct. 13	.33	.31	Considerable	Musty
“ “ “	Nov. 7	.25	.23	Slight	“
Average. . . . .		.29	.53		
Hamilton, above town.	April 25	.16	.09	Considerable	Vegetative
“ “ “	May 28	.28	5.60	Much	Earthy
“ “ “	June 27	.27	2.80	“	Vegetative
“ “ “	July 19	.28	2.45	“	Earthy
“ “ “	Aug. 21	.28	.93	Considerable	“
“ “ “	Sept. 19	.25	.25	Slight	Vegetative
“ “ “	Oct. 13	.43	.43	Considerable	Faint musty
“ “ “	Nov. 7	.25	.25	Slight	“ “
Average. . . . .		.28	1.60		
Hamilton, below town.	April 25	.18	.09	Considerable	Musty
“ “ “	May 28	.28	5.40	Much	Earthy
“ “ “	June 27	.27	1.80	“	Oily
“ “ “	July 19	.26	1.40	“	Earthy
“ “ “	Aug. 21	.28	.75	Considerable	“
“ “ “	Sept. 19	.25	.23	Slight	Faint musty
“ “ “	Oct. 13	.33	.44	Considerable	“ “
“ “ “	Nov. 7	.27	.20	Slight	Musty
Average. . . . .		.26	1.29		
Cleves, below town.	April 25	.16	.11	Considerable	Vegetative
“ “ “	May 29	.23	5.20	Much	Earthy and faint musty
“ “ “	June 27	.30	2.00	“	Earthy and faint musty
“ “ “	July 20	.30	5.40	“	Vegetative, earthy
“ “ “	Aug. 21	.28	.93	Considerable	Earthy
“ “ “	Sept. 18	.20	.34	Slight	“
“ “ “	Oct. 13	.31	.38	Considerable	Earthy, vegetative
“ “ “	Nov. 8	.27	.24	Slight	Earthy
Average. . . . .		.26	1.82		

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
14.6	2.3	202.4	2.2	204.6	370
2.2	4.5	232.4	20.2	252.6	460
0.6	1.9	198.0	4.0	202.0	593
0.4	7.3	222.0	39.8	261.8	484
Trace	4.2	240.8	17.8	258.6	446
None	9.3	239.8	None	239.8	463
Trace	5.1	186.8	27.6	214.4	434
0.3	7.8	242.2	12.2	254.4	435
2.3	5.3	220.5	15.4	235.9	461
13.3	1.8	201.2	3.8	205.0	316
8.0	0.1	122.4	7.4	129.8	1794
4.3	1.1	186.4	None	186.4	621
0.4	2.1	180.2	22.2	202.4	592
Trace	3.6	187.2	21.0	208.2	436
0.3	7.1	226.0	8.2	234.2	416
Trace	3.6	179.4	29.2	208.6	418
Trace	5.5	227.2	19.6	246.8	417
3.3	3.1	188.7	13.9	202.6	626
11.5	3.3	206.8	15.8	222.6	347
6.2	2.1	140.4	2.8	143.2	1547
1.5	3.9	230.0	35.6	265.6	467
0.6	4.0	195.8	30.0	225.8	500
Trace	3.8	182.8	7.2	190.0	383
0.3	9.7	230.6	12.6	243.2	414
Trace	4.4	181.2	None	181.2	371
0.3	6.7	227.6	11.8	239.4	381
2.5	4.7	199.4	14.5	213.9	551
13.3	2.2	203.4	7.6	211.0	369
3.4	0.7	121.4	15.2	136.6	1721
2.6	4.3	225.6	28.0	253.6	674
0.4	2.2	165.0	28.8	193.8	2066
0.2	3.6	172.2	0.6	172.8	430
0.5	7.2	232.4	11.4	243.8	450
14.6	4.6	187.4	None	187.4	412
0.4	6.5	226.6	7.8	234.4	381
2.8	3.9	191.7	12.4	204.1	813

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
LITTLE MIAMI RIVER. Samples collected in 1900.					
South Charleston, above town.	May 28	.26	.13	Slight	Earthy
" " " "	June 26	.40	.34	Considerable	Vegetative
" " " "	July 17	.30	.30	"	"
" " " "	Aug. 20	.30	.31	"	Earthy
" " " "	Oct. 18	.23	.24	"	Vegetative
" " " "	Nov. 7	.29	.25	"	Vegetative, earthy
Average.....		.30	.26		
Xenia, above town.....	April 26	.20	.12	Slight	Vegetative
" " "	May 28	.28	.20	Considerable	"
" " "	June 28	.33	.40	"	"
" " "	July 17	.30	.34	"	Marked vegetative
" " "	Aug. 22	.43	.27	"	Vegetative
" " "	Sept. 17	.16	.14	Slight	"
" " "	Oct. 18	.35	.13	Considerable	Faint, musty
" " "	Nov. 9	.65	.08	Slight	Vegetative
Average.....		.34	.21		
Xenia, below town.....	April 26	.26	.12	Slight	Marked vegetative
" " "	May 28	.32	.22	Considerable	Vegetative
" " "	June 28	.33	.40	"	"
" " "	July 17	.28	.26	"	Marked vegetative
" " "	Aug. 22	.38	.23	"	Vegetative
" " "	Sept. 17	.17	.15	Slight	"
" " "	Oct. 18	.33	.14	Considerable	Faint, musty
" " "	Nov. 9	.58	.10	Slight	Vegetative
Average.....		.33	.20		
Loveland, above town.....	April 24	.18	.11	Considerable	Marked vegetative
" " "	May 29	.30	.75	Much	Earthy
" " "	June 26	.15	.52	Considerable	Faint, sour
" " "	July 17	.13	.50	"	Vegetative
" " "	Aug. 20	.33	1.05	"	Earthy, vegetative
" " "	Sept. 17	.20	.26	Slight	Earthy
" " "	Oct. 19	.18	.23	Considerable	Vegetative
" " "	Nov. 9	.26	.16	Slight	Earthy
Average.....		.22	.45		
Linwood, below town.....	April 24	.13	.10	Considerable	Vegetative
" " "	May 29	.25	5.20	Much	Earthy
" " "	June 26	.23	.42	Considerable	Vegetative
" " "	July 19	.25	7.00	Much	Earthy

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
5.3	Trace	225.8	66.0	291.8	354
3.0	Trace	239.4	39.8	279.2	390
0.3	1.5	290.2	7.4	297.6	438
Trace	None	221.8	36.2	258.0	349
None	None	223.2	None	223.2	362
None	4.0	266.8	None	266.8	423
1.4	0.9	244.5	24.9	269.4	386
5.3	1.1	223.8	18.4	242.2	335
3.1	0.5	234.8	27.8	262.6	396
3.0	0.8	250.8	None	250.8	423
0.1	0.7	260.8	None	260.8	374
0.1	Trace	230.2	22.2	252.4	369
0.3	1.4	235.8	None	235.8	315
Trace	0.8	269.8	None	269.8	386
0.5	1.9	287.2	None	287.2	368
1.5	0.9	249.1	8.5	257.6	371
5.8	1.6	240.2	13.8	254.0	362
3.9	4.3	254.4	7.0	261.4	418
4.4	2.2	221.6	32.2	253.8	383
1.6	3.2	256.6	None	256.6	375
Trace	0.8	236.8	None	236.8	344
Trace	1.9	242.4	None	242.4	388
Trace	1.7	252.4	None	252.4	380
0.4	2.6	281.0	None	281.0	378
2.0	2.3	248.2	6.6	254.8	378
5.8	1.1	194.2	20.2	214.4	316
2.3	0.8	157.6	15.2	172.8	483
1.8	2.2	238.8	12.4	251.2	389
1.3	2.6	219.6	11.2	230.8	350
1.3	None	128.2	20.6	148.8	338
None	2.8	210.0	None	210.0	316
None	2.9	224.0	None	224.0	378
Trace	2.7	231.2	None	231.2	343
1.5	1.9	200.4	9.9	210.3	364
2.5	2.6	190.6	19.4	210.0	308
0.8	0.5	106.6	26.4	133.0	2195
0.4	3.2	212.8	3.0	215.8	345
0.4	1.3	127.6	25.2	152.8	1913

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
LITTLE MIAMI RIVER—Concluded.					
Linwood, below town.....	Aug. 20	.23	1.20	Considerable	Earthy
" " "	Sept. 18	.22	.30	Slight	Earthy, vegetative
" " "	Oct. 13	.32	.45	Considerable	Earthy
" " "	Nov. 8	.17	.11	Slight	"
Average.....		.22	1.85		
EAST FORK OF LITTLE MIAMI RIVER. Samples collected in 1900.					
Batavia, above town.....	April 25	.25	.17	Considerable	Faint earthy
" " "	June 1	.33	.24	"	Vegetative
" " "	June 27	.25	.18	Slight	"
" " "	July 20	.25	.22	Considerable	Sour
" " "	Aug. 21	.28	1.14	"	Earthy
" " "	Sept. 19	.23	.28	Slight	Vegetative
" " "	Oct. 19	.28	.38	Considerable	"
" " "	Nov. 8	.28	.18	Slight	Faint vegetative
Average.....		.27	.35		
Batavia, below town.....	April 25	.25	.16	Considerable	Faint earthy
" " "	June 1	.33	.24	"	Vegetative
" " "	June 27	.28	.18	Slight	"
" " "	July 20	.25	.20	Considerable	"
" " "	Aug. 21	.28	1.12	"	Earthy
" " "	Sept. 19	.23	.27	Slight	Vegetative
" " "	Oct. 19	.32	.38	Considerable	"
" " "	Nov. 8	.25	.17	Slight	Faint musty
Average.....		.27	.34		
BLACK FORK OF MOHICAN RIVER. Samples collected in 1899.					
Shelby, above town.....	May 3	.18	.07 ¹	Slight	Faint woody
" " "	May 29	.28	2.00	Considerable	Earthy
" " "	June 27	.25	.05 ¹	Very slight	Vegetative
" " "	July 18	.30	.42	Considerable	Earthy
" " "	Aug. 17	.20	.07	Very slight	Vegetative
" " "	Sept. 18	.16	.13	Slight	"
" " "	Oct. 12	.25	.06 ¹	Very slight	None
" " "	Nov. 17	.45	.12	Slight	Earthy
Average.....		.26	.36		
Shelby, below town.....	May 3	.12	.04 ¹	Slight	Faint sour
" " "	May 29	.32	.62	Considerable	Earthy
" " "	June 27	.17	.06 ¹	Slight	Faint sour
" " "	July 18	.60	.27	Considerable	Vegetative

¹Turbidity rod on bottom of streams with wire still visible.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.4	Trace	108.2	None	108.2	352
Trace	3.4	205.8	None	205.8	326
Trace	3.1	161.6	None	161.6	356
0.2	4.1	229.2	8.6	237.8	302
0.5	2.3	167.8	10.3	178.1	679
0.1	2.1	154.8	39.0	193.8	270
0.6	0.5	160.8	42.0	202.8	258
0.5	0.5	149.4	23.4	172.8	257
0.2	Trace	167.6	None	167.6	251
Trace	None	80.0	None	80.0	307
None	1.1	135.4	50.2	185.6	238
None	2.2	111.4	10.2	121.6	251
0.4	4.6	121.8	6.8	128.6	233
0.2	1.4	135.1	21.4	156.5	258
0.1	2.4	157.6	63.8	221.4	299
0.7	1.1	161.2	19.4	180.6	277
0.5	0.9	143.2	73.8	217.0	261
0.1	0.9	195.2	None	195.2	262
Trace	Trace	80.2	8.2	88.4	353
None	1.8	139.0	None	139.0	246
None	3.0	115.0	None	115.0	243
0.2	4.4	124.4	23.2	147.6	230
0.2	1.8	139.5	23.5	163.0	271
0.3	4.1	197.6	33.0	230.6	406
0.5	Trace	120.8	13.9	134.7	956
0.4	1.5	176.8	33.8	210.6	354
0.3	0.9	153.6	84.8	238.4	407
0.1	4.3	191.6	81.6	273.2	428
0.1	2.1	191.4	59.2	250.6	411
None	1.3	227.4	48.2	275.6	414
0.1	1.7	181.8	98.6	280.4	468
0.2	2.0	180.1	56.6	236.7	480
0.3	11.7	115.8	100.9	216.7	538
0.6	7.8	103.0	54.1	157.1	435
0.5	12.5	137.8	87.0	224.8	473
5.8	6.3	110.2	88.8	199.0	383

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
BLACK FORK OF MOHICAN RIVER—Concluded.					
Shelby, below town.....	Aug. 17	.20	.07	Very slight	Strong vegetative
" " "	Sept. 18	.20	.27	Slight	Cattle
" " "	Nov. 17	.20	.08	"	Mouldy
Average.....		.26	.20		
ROCKY FORK OF MOHICAN RIVER. Samples collected in 1899.					
Mansfield, above town.....	May 4	.15	.06	Slight	None
" " "	May 29	.42	2.90	Considerable	Earthy
" " "	June 27	.20	.08	Very slight	None
" " "	July 18	.25	.16	" "	Vegetative
" " "	Aug. 17	.15	.05 ¹	" "	None
" " "	Sept. 18	.18	.10	Slight	Vegetative
" " "	Oct. 12	.10	.09	Very slight	None
" " "	Nov. 17	.15	.12	Slight	Slight vegetative
Average.....		.20	.44		
Mansfield, below town.....	May 4	.23	.07	Considerable	Foul
" " "	May 29	.28	3.00	Much	"
" " "	June 27	.23	.10	Slight	"
" " "	July 18	.25	.21	Considerable	"
" " "	Aug. 17	.18	.09	"	"
" " "	Sept. 18	.25	.09	Slight	Foul oily
" " "	Oct. 12	.20	.11	Considerable	" "
" " "	Nov. 17	.22	.25	"	" "
Average.....		.23	.49		
MUSKINGUM RIVER. Samples collected in 1899.					
Coshocton, below town.....	May 6	.20	.16	Slight	None
" " "	May 25	.33	.28	"	"
" " "	June 23	.22	.80	Considerable	Earthy
" " "	July 24	.18	.22	"	Tea
" " "	Aug. 29	.18	.23	"	Musty
" " "	Sept. 26	.20	.30	"	Earthy
" " "	Oct. 10	.15	.19	Slight	Faint musty
" " "	Nov. 14	.15	.08	"	Earthy
Average.....		.20	.28		
Zanesville, above town.....	April 29	.20	.40	Considerable	None
" " "	May 23	.25	.90	"	Faint earthy
" " "	June 21	.25	4.30	"	Earthy
" " "	July 27	.25	1.00	"	"
" " "	Aug. 31	.25	.48	"	Musty

¹Turbidity rod on bottom with wire still visible.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.2	28.3	57.2	327.6	384.8	810
0.3	32.1	90.4	350.6	441.0	959
0.3	8.7	77.4	225.6	303.0	598
1.3	15.3	98.8	176.4	275.2	599
0.1	1.3	197.6	46.9	244.5	421
0.4	2.8	54.5	Trace	54.5	1168
0.3	1.2	171.4	27.4	198.8	370
0.2	2.4	171.6	64.2	235.8	376
None	12.4	188.4	58.4	246.8	394
0.2	0.5	194.4	79.8	274.2	473
0.3	0.6	207.8	93.2	301.0	425
1.4	1.7	172.2	101.8	274.0	470
0.4	2.9	169.7	59.0	228.7	512
0.4	14.4	201.6	27.5	229.1	404
0.6	10.9	130.3	49.3	179.6	1535
0.5	31.4	208.7	30.2	238.9	466
1.5	17.4	188.0	61.8	249.8	407
None	20.9	34.8	36.6	71.4	441
1.4	17.5	27.4	57.0	84.4	495
0.1	12.6	214.6	78.8	293.4	471
0.2	8.5	163.6	103.0	266.6	448
0.6	16.7	146.1	55.5	201.6	583
0.1	8.3	104.6	33.8	138.4	266
0.2	6.5	79.1	13.3	92.4	293
0.4	15.4	102.5	69.6	172.1	367
0.4	25.5	117.6	31.8	149.4	321
0.1	15.2	138.2	79.0	217.2	319
0.2	24.2	137.2	29.2	166.4	364
0.3	32.1	144.0	82.6	226.6	382
0.2	27.9	139.8	54.4	194.2	318
0.2	19.4	120.4	49.2	169.6	329
0.5	2.6	93.0	80.4	173.4	353
0.3	3.6	78.9	44.5	123.4	424
0.4	1.1	51.7	30.4	82.1	1361
0.2	9.5	95.8	21.6	117.4	363
0.4	9.7	166.6	23.2	189.8	328

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
MUSKINGUM RIVER—Concluded.					
Zanesville, above town.....	Sept. 28	.30	.90	Considerable	Earthy
“ “ “	Oct. 18	.25	.26	“	“
“ “ “	Nov. 23	.25	.25	Very slight	None
Average.....		.25	1.06		
Zanesville, below town.....	April 29	.20	.40	Considerable	None
“ “ “	May 23	.25	.50	“	Faint musty
“ “ “	June 21	.25	4.00	“	Earthy
“ “ “	July 27	.25	1.00	“	“
“ “ “	Aug. 31	.25	.58	“	Musty
“ “ “	Sept. 28	.30	.85	“	Faint oily
“ “ “	Oct. 18	.22	.22	“	Musty
“ “ “	Nov. 23	.20	.26	Very slight	Faint mouldy
Average.....		.24	.98		
McConnelsville, above town..	April 28	.10	.20	Considerable	None
“ “ “ ...	May 24	.28	.55	“	Faint earthy
“ “ “ ...	June 23	.20	3.70	“	Earthy
“ “ “ ...	July 25	...	.45	Slight	Vegetative, earthy
“ “ “ ...	Aug. 30	.22	.28	“	Vegetative
“ “ “ ...	Sept. 27	.20	.17	“	Earthy
“ “ “ ...	Oct. 17	.10	.14	“	Vegetative, earthy
“ “ “ ...	Nov. 22	.20	.14	Very slight	None
Average.....		.19	.70		
Marietta, above town.....	April 28	.10	.14	Slight	Faint woody
“ “ “	May 24	.25	.90	Considerable	“ earthy
“ “ “	June 22	.22	3.50	“	“ “
“ “ “	July 25	.28	.45	“	Vegetative
“ “ “	Aug. 30	.20	.20	Slight	Earthy
“ “ “	Sept. 27	.25	.20	“	“
“ “ “	Oct. 17	.10	.27	Very slight	Faint sour
“ “ “	Nov. 22	.10	.13	“ “	None
Average.....		.19	.70		
NIMISHILLEN CREEK. Samples collected in 1899.					
Canton, below town.....	May 5	.40	.09 ¹	Slight	None
“ “ “	May 30	.50	.32	Considerable	Faint, musty
“ “ “	June 28	.15	.11 ¹	Slight	Musty
“ “ “	July 19	.25	.08 ¹	“	Strong musty

¹Stream so shallow turbidity stick rested on bed with wire still visible.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.1	16.1	137.0	43.2	180.2	440
0.2	21.1	145.8	14.8	160.6	385
0.8	16.1	145.2	29.4	174.6	334
0.4	10.0	114.2	35.9	150.1	498
0.6	5.6	93.7	31.2	124.9	261
0.3	5.6	59.4	41.6	101.0	305
0.6	1.4	60.9	14.0	74.9	1496
0.3	6.5	90.2	8.2	98.4	442
0.0	10.5	154.8	41.8	196.6	495
0.3	13.7	152.2	12.0	164.2	511
0.2	18.2	166.2	3.2	169.4	382
0.5	14.9	172.4	35.2	207.6	349
0.4	9.6	118.7	23.4	142.1	530
0.4	5.8	101.1	56.8	157.9	269
0.4	3.8	73.0	50.0	123.0	304
0.5	2.1	44.5	7.6	52.1	1784
1.1	11.8	90.8	21.8	112.6	296
0.2	14.8	147.2	40.0	187.2	329
0.4	14.3	152.2	None	152.2	306
0.3	15.7	152.2	31.8	184.0	308
0.4	19.0	142.2	49.0	191.2	315
0.4	10.9	112.9	32.1	145.0	489
0.4	5.7	112.4	57.9	170.3	275
0.4	2.9	71.8	22.4	94.2	396
0.5	9.3	93.9	52.0	145.9	1017
0.2	8.2	93.6	17.0	110.6	264
0.2	8.9	122.2	55.0	177.2	245
0.2	13.5	143.6	6.4	150.0	304
0.1	11.2	146.8	62.0	208.8	300
0.7	17.9	144.2	39.4	183.6	322
0.4	9.7	116.1	39.0	155.1	390
0.3	5.9	158.4	9.9	168.3	304
0.7	1.3	52.1	5.4	57.5	225
3.7	12.3	156.0	56.8	212.8	377
0.4	14.3	179.2	44.8	224.0	335

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
NIMISHILLEN CREEK—Concluded.					
Canton, below town.....	Aug. 19	.25	.08	Very slight	Foul
“ “ “	Sept. 19	.22	.26	Considerable	Very musty
“ “ “	Oct. 11	.20	.09	Slight	Foul
“ “ “	Nov. 16	.25	.09	Slight	Musty
Average.....		.28	.18		
NIMISHILLEN CREEK (WEST BRANCH). Samples collected in 1899.					
Canton, above town.....	May 5	.25	.06	Slight	Faint earthy
“ “ “	May 30	.50	.30	Considerable	“ musty
“ “ “	June 28	.15	.03 ⁱ	Very slight	None
“ “ “	July 19	.23	.03 ¹	“ “	Vegetative
“ “ “	Aug. 19	.10	.03 ¹	Trace	“
“ “ “	Sept. 19	.13	.06	“	“
“ “ “	Oct. 11	.10	.03 ¹	“	“
“ “ “	Nov. 16	.35	.09 ¹	Slight	“
Average.....		.23	.08		
OHIO RIVER. ² Samples collected in 1901. Untreated supplies.					
Wellsville, hydrant.....	April 16	.29	96	Considerable	Faint earthy
“ “ “	June 24	.20	c948	“	Distinct earthy
“ “ “	July 17	.45	58	Decided	“ vegetative
“ “ “	Aug. 12	.32	Slight	Slight	Faint musty
“ “ “	Aug. 31	.36	101	Decided	Distinct earthy
“ “ “	Sept. 6	.45	d110	Much	“ “
“ “ “	Sept. 13	.40	173	Decided	Faint vegetative
“ “ “	Oct. 11	.35	Slight	Slight	Distinct “
“ “ “	Dec. 11	.35	78	Decided	“ earthy
Average.....		.35	284		
Martins Ferry, hydrant.....	April 17	.28	46	Considerable	Faint earthy
“ “ “	June 24	.22	c567	“	Distinct “
“ “ “	July 17	.35	58	Decided	“ vegetative
“ “ “	Aug. 12	.28	Very slight	Slight	“ “
“ “ “	Oct. 14	.30	29	“	None
“ “ “	Dec. 11	.38	58	“	Faint earthy
Average.....		.30	126		
Bellaire, river.....	April 18	.28	63	Considerable	Faint vegetative
“ “ “	June 24	.22	c711	“	Distinct earthy
“ “ “	July 17	.35	73	“	“ vegetative

¹Stream so shallow turbidity stick rested on bed with wire still visible.²The significance of the letters used in the turbidity column of the Ohio River results is as follows: Turbidity obtained by diluting river water with clear water, c = ratio of 1 volume of river water to 3 volumes of clear water; d = 1 to 4; e = 1 to 5; f = 1 to 6; h = 1 to 8; l = 1 to 12; r = 1 to 18. The letter u in a column means undetermined. Turbidities are in terms of the silica standard. See page 161.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.1	22.7	170.2	82.8	253.0	408
0.6	7.5	153.0	65.4	218.4	332
0.7	14.4	198.4	67.6	266.0	395
3.9	4.8	146.2	69.2	215.4	367
1.3	10.4	151.7	50.2	201.9	343
0.3	2.8	147.0	55.4	202.4	315
0.6	0.5	50.7	15.3	66.0	192
3.5	3.2	160.1	None	160.1	286
0.2	3.1	169.6	30.0	199.6	293
3.1	2.8	179.2	76.8	256.0	297
0.2	1.1	171.4	15.0	186.4	273
Trace	0.9	179.0	17.8	196.8	281
4.4	1.2	147.8	70.6	218.4	418
1.5	2.0	150.6	35.1	185.7	294
4.4	13.6	11.	35.	46.	197
Trace	14.6	23.	.....	23.	712
1.0	22.7	29.	.....	29.	222
Trace	30.5	37.	.....	37.	231
Trace	11.8	27.	.....	27.	176
Trace	13.1	32.	.....	32.	1228
0.2	19.3	25.	.....	25.	276
Trace	19.8	32.	.....	32.	169
0.1	14.8	19.	.....	19.	153
0.6	17.8	26.	.....	26.	374
0.7	9.8	22.	53.	75.	171
Trace	17.0	36.	.....	36.	375
0.9	19.0	34.	.....	34.	234
0.3	31.4	43.	.....	43.	217
Trace	23.3	36.	.....	36.	188
0.3	10.6	20.	.....	20.	143
0.4	18.5	32.	.....	32.	221
Trace	6.6	19.	38.	57.	177
Trace	15.2	30.	.....	30.	408
1.0	19.9	34.	.....	34.	251

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
OHIO RIVER. ¹ Untreated supplies—Concluded.					
Bellaire, hydrant.....	April 18	.28	46	Considerable	Faint vegetative
" "	June 24	.22	c603	"	Distinct "
" "	July 17	.40	73	"	" "
" "	Aug. 10	.32	54	Decided	" "
" "	Sept. 2	.30	358	Considerable	" earthy
" "	Sept. 12	.42	106	Decided	Faint vegetative
" "	Oct. 8	.24	Slight	Slight	Distinct "
" "	Dec. 10	.40	83	Decided	" "
Average.....		.32	165		
Ironton, hydrant.....	May 16	.24	562	Considerable	Distinct earthy
" "	July 23	.35	d1632	Much	" "
" "	Aug. 30	.30	470	Considerable	" musty
" "	Nov. 21	.35	111	Slight	" earthy
" "	Dec. 12	.50	302	Considerable	" "
Average.....		.35	615		
Portsmouth, hydrant.....	May 17	.4	1084	Considerable	Earthy
" "	June 27	.40	r13068	Much	"
" "	July 23	.50	h2248	"	"
" "	Aug. 19	.33	e890	Considerable	"
" "	Dec. 10	.40	153	"	"
Average.....		.37	3489		
OHIO RIVER. Subsidized supplies. Samples collected in 1901.					
East Liverpool, river.....	April 16	.29	126	Considerable	Faint earthy
" " "	June 25	.28	249	"	Earthy
" " "	July 17	.43	78	Decided	Vegetative
" " "	Aug. 12	.28	u Slight	Slight	Vegetative
" " "	Sept. 4	.36	207	Decided	Faint earthy
" " "	Sept. 11	.36	96	"	" vegetative
" " "	Oct. 7	.35	u Slight	Slight	Vegetative
Average.....		.34	108		
East Liverpool, hydrant.....	April 16	.39	83	Slight	Faint earthy
" " "	June 25	.23	207	Considerable	Vegetative and earthy
" " "	July 17	.25	46	Slight	Faint vegetative
" " "	Aug. 12	.50	Very slight	Very slight	" "

¹The significance of the letters used in the turbidity column of the Ohio River results is as follows: Turbidity obtained by diluting river water with clear water, c = ratio of 1 volume of river water to 3 volumes of clear water; d = 1 to 4; e = 1 to 5; f = 1 to 6; h = 1 to 8; l = 1 to 12; r = 1 to 18. The letter u in a column means undetermined. Turbidities are in terms of the silica standard.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
Trace	8.2	25.	42.	67.	177
"	18.8	35.	.....	35.	378
1.0	19.0	36.	.....	36.	270
1.0	32.0	44.	.....	44.	250
Trace	13.6	36.	.....	36.	389
0.2	16.2	33.	.....	33.	252
0.4	22.2	37.	.....	37.	209
0.2	10.0	17.	.....	17.	140
0.4	17.5	35.	.....	35.	258
Trace	11.1	22.	43.	65.	412
0.2	16.0	38.	.....	38.	719
Trace	18.4	31.	.....	31.	453
"	38.3	50.	.....	50.	292
0.2	14.6	19.	.....	19.	491
0.1	19.7	32.	.....	32.	473
Trace	9.9	29.	62.	91.	694
0.9	3.1	26.	.....	26.	4500
1.3	13.1	30.	.....	30.	612
0.4	7.3	35.	.....	35.	407
Trace	16.2	19.	.....	19.	241
0.5	9.9	28.	.....	28.	1291
4.9	15.4	9.	44.	53.	178
Trace	16.8	33.	.....	33.	257
0.7	23.4	33.	.....	33.	244
Trace	30.7	35.	.....	35.	241
0.2	17.8	25.	.....	25.	192
0.4	16.3	34.	.....	34.	168
0.4	22.7	40.	.....	40.	218
0.9	20.4	30.	.....	30.	214
0.5	7.8	8.	23.	31.	112
Trace	17.6	30.	.....	30.	243
0.4	24.0	30.	.....	30.	218
Trace	30.7	38.	.....	38.	220

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
OHIO RIVER, ¹ Subsided supplies—Continued.					
East Liverpool, hydrant.....	Sept. 4	.37	389	Decided	Earthy
“ “ “	Sept. 11	.39	73	“	Faint vegetative
“ “ “	Oct. 7	.28	Slight	Slight	Vegetative
“ “ “	Dec. 10	.50	92	Decided	“
Average.....		.35	111		
Toronto, river.....	April 17	.28	78	Considerable	Faint earthy
“ “	June 24	.20	d657	“	Earthy
“ “	July 18	.29	58	Slight	Faint earthy and vegetative
“ “	Aug. 17	.21	u Slight	“	Faint vegetative
Average.....		.25	198		
Toronto, hydrant.....	April 17	.26	50	Slight	Faint earthy
“ “	June 24	.22	96	Decided	Vegetative
“ “	July 18	.25	u Slight	Trace	Faint earthy
“ “	Aug. 17	.22	u Very slight	Very slight	Faint
Average.....		.24	37		
Steubenville, river.....	April 17	.28	63	Considerable	Faint vegetative
“ “	June 28	.30	470	“	Earthy
“ “	July 17	.35	37	Decided	Faint vegetative
“ “	Aug. 12	.30	u Very slight	Very slight	Trace
“ “	Oct. 9	off h ¹ h	136	Considerable	Strong foul
“ “	Dec. 11	.38	158	“	Vegetative and earthy
Average.....		.32	144		
Steubenville, hydrant.....	April 17	.27	37	Slight	Faint earthy
“ “	June 24	.20	68	“	Vegetative
“ “	July 17	.30	Very slight	Trace	None
“ “	Aug. 12	.8	None	None	Trace
“ “	Oct. 9	.26	Trace	Trace	None
“ “	Dec. 11	.30	Very slight	Very slight	“
Average.....		.23			
Marietta, river.....	May 14	.26	645	Considerable	Earthy
“ “	June 27	.35	336	“	“
“ “	July 23	.35	126	“	Vegetative
“ “	Aug. 19	.25	83	Slight	“

¹The significance of the letters used in the turbidity column of the Ohio River results is as follows: Turbidity obtained by diluting river water with clear water, c = ratio of 1 volume of river water to 3 volumes of clear water; d = 1 to 4; e = 1 to 5; f = 1 to 6; h = 1 to 8; l = 1 to 12; r = 1 to 18. The letter u in a column means undetermined. Turbidities are in terms of silica standard.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
Trace	18.7	22.	.....	22.	241
None	17.0	29.	.....	29.	143
0.5	21.2	39.	.....	39.	195
0.7	19.7	19.	.....	19.	189
0.2	19.6	27.	.....	27.	195
1.1	9.0	11.	35.	46.	178
Trace	12.7	26.	.....	26.	527
1.9	24.4	30.	.....	30.	224
0.4	33.6	30.	.....	30.	269
0.8	19.9	24.	.....	24.	299
0.7	7.0	12.	42.	54.	131
Trace	10.5	23.	.....	23.	184
1.3	18.1	28.	.....	28.	187
Trace	29.3	33.	.....	33.	228
0.5	16.2	24.	.....	24.	182
0.3	9.7	14.	34.	48.	181
Trace	9.7	20.	.....	20.	382
0.8	32.4	26.	.....	26.	236
Trace	31.4	u	.....	.....	u
None	.....	33.	139.	162.	684
0.2	30.0	27.	.....	27.	284
0.2	22.6	24.	.....	24.	353
0.5	6.0	19.	40.	59.	106
Trace	9.6	21.	.....	21.	167
0.6	17.9	23.	.....	23.	172
0.1	39.4	40.	.....	40.	193
0.4	19.5	32.	33.	65.	137
0.3	6.2	u	.....	.....	u
0.4	16.4	27.	.....	27.	155
None	10.5	14.	25.	39.	820
1.2	15.7	29.	.....	29.	357
0.8	18.0	12.	.....	12.	276
0.3	37.3	43.	.....	43.	313

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
OHIO RIVER. ¹ Subsided supplies—Concluded.					
Marietta, river.....	Sept. 9	.26	131	Decided	Faint
“ “	Sept. 28	.45	42	Slight	Faint vegetative
“ “	Oct. 11	.35	29	Decided	Vegetative
“ “	Dec. 11	.45	126	“	“
Average.....		.34	190		
Marietta, hydrant.....	May 14	.24	429	Considerable	Earthy
“ “	June 27	.35	316	“	“
“ “	July 23	.32	92	Slight	Vegetative and earthy
“ “	Aug. 19	.16	73	“	Decided oily
“ “	Sept. 9	.14	201	Decided	Strong
“ “	Sept. 28	.30	46	“	Stale vegetative
“ “	Oct. 11	.15	46	“	Faint putrefactive
“ “	Dec. 11	.45	121	“	Vegetative
Average.....		.26	166		
New Richmond, river.....	May 18	.30	316	Considerable	Earthy
“ “ “	June 29	.26	e3330	Much	“
“ “ “	July 23	.43	287	Slight	“
“ “ “	Aug. 19	.29	316	Decided	Vegetative
“ “ “	Oct. 8	.20	Trace	Trace	Trace
“ “ “	Dec. 11	.50	141	Decided	Earthy
Average.....		.33	732		
New Richmond hydrant.....	May 18	.25	58	Slight	None
“ “ “	June 29	.23	f 1896	Considerable	Earthy
“ “ “	July 23	.40	Slight	Trace	Faint
“ “ “	Aug. 19	.24	“	Very slight	Faint vegetative
“ “ “	Oct. 8	.26	Trace	Trace	Trace
“ “ “	Dec. 11	.18	Slight	Very slight	None
Average.....		.26	326		
OHIO RIVER. Filtered supplies. Samples collected in 1901.					
Mingo Junction, river.....	April 17	.30	63	Considerable	Faint vegetative
“ “ “	June 25	.35	207	“	Earthy
“ “ “	July 17	.40	63	“	Faint musty
“ “ “	Aug. 13	.27	u Slight	Slight	Oily
“ “ “	Oct. 31	.60	88	“	Strong, bad
Average.....		.38	84		

¹The significance of the letters used in the turbidity column of the Ohio River results is as follows: Turbidity obtained by diluting river water with clear water, c = ratio of 1 volume of river water to 3 volumes of clear water; d = 1 to 4; e = 1 to 5; f = 1 to 6; h = 1 to 8; l = 1 to 12; r = 1 to 18. The letter u in a column means undetermined. Turbidities are in terms of silica standard.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
Trace	14.4	25.	.....	25.	178
"	12.2	25.	.....	25.	155
"	26.8	32.	.....	32.	184
"	27.8	19.	.....	19.	281
0.3	20.3	25.	.....	25.	320
Trace	12.3	22.	55.	77.	342
1.0	15.1	29.	.....	29.	325
0.3	21.7	21.	.....	21.	206
0.3	43.7	46.	.....	46.	313
Trace	17.5	33.	.....	33.	179
"	12.4	42.	.....	42.	176
"	23.9	38.	.....	38.	176
"	11.8	17.	.....	17.	208
0.2	19.8	31.	.....	31.	241
Trace	8.6	35.	71.	106.	495
"	4.5	36.	.....	36.	827
0.3	9.9	46.	.....	46.	182
Trace	5.3	35.	.....	35.	273
0.4	10.5	43.	.....	43.	128
0.2	15.1	24.	.....	24.	220
0.1	9.0	37.	.....	37.	354
Trace	7.4	42.	34.	76.	169
"	3.0	38.	.....	38.	329
0.5	8.0	56.	.....	56.	129
Trace	10.3	59.	.....	59.	181
0.5	10.4	44.	.....	44.	132
0.3	19.9	49.	.....	49.	172
0.2	9.8	48.	.....	48.	185
Trace	7.8	13.	14.	27.	181
"	16.9	25.	41.	66.	343
1.4	27.0	32.	49.	81.	251
0.6	36.9	44.	51.	95.	289
None	39.2	56.	49.	105.	302
0.4	25.6	34.	41.	75.	269

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
OHIO RIVER, ¹ Filtered supplies—Continued.					
Mingo Junction, hydrant.....	April 17	.28	Trace	Trace	Trace
“ “ “	June 25	.24	Trace	Very slight	None
“ “ “	July 17	.8	“	Trace	“
“ “ “	Aug. 13	.5	None	None	Raw oysters
“ “ “	Oct. 31	.0	“	“	None
Average.....		.13			
Pomeroy, river.....	May 15	.22	515	Considerable	Earthy
“ “	June 27	.40	1 4668	Much	“
“ “	July 23	.45	666	Considerable	“
“ “	Aug. 19	.19	Slight	Very slight	Oily
“ “	Sept. 24	.50	249	Decided	Earthy
“ “	Dec. 23	.55	189	“	“
Average.....		.39	1048		
Pomeroy, hydrant.....	May 15	.10	Trace	Trace	None
“ “	June 27	.20	Slight	Slight	Faint
“ “	July 23	.10	“	Very slight	Trace
“ “	Aug. 19	.18	Trace	Trace	None
“ “	Sept. 24	.5	None	None	“
“ “	Dec. 23	.0	“	“	“
Average.....		.10			
Gallipolis, river.....	May 16	.24	429	Considerable	Earthy
“ “	July 1	.26	e2350	“	“
“ “	July 23	.35	d1716	Much	“
“ “	Aug. 19	.25	281	Considerable	“
“ “	Sept. 21	.35	e906	“	“
“ “	Oct. 9	.28	u Slight	Slight	Vegetative
“ “	Dec. 14	.35	302	Considerable	Vegetative and earthy
Average.....		.30	826		
Gallipolis, hydrant.....	May 16	.8	None	None	None
“ “	July 1	.20	Trace	Very slight	“
“ “	July 23	.10	Trace	“ “	“
“ “	Aug. 19	.13	“	“ “	Faint vegetative
“ “	Sept. 21	.10	None	None	None
“ “	Oct. 9	Trace	“	“	“
“ “	Dec. 14	.10	“	“	“
Average.....		.10			

¹The significance of the letters used in the turbidity column of the Ohio River results is as follows: Turbidity obtained by diluting river water with clear water, c = ratio of 1 volume of river water to 3 volumes of clear water; d = 1 to 4; e = 1 to 5; f = 1 to 6; h = 1 to 8; l = 1 to 12; r = 1 to 18. The letter u in a column means undetermined. Turbidities are in terms of silica standard.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
12.0	19.8	47.	45.	92.	215
14.2	21.9	55.	74.	129.	265
19.5	22.6	60.	92.	152.	279
21.2	32.8	74.	109.	183.	347
12.4	30.5	76.	96.	172.	327
15.9	25.5	62.	83.	145.	287
None	11.7	28.	32.	60.	1005
0.9	8.7	40.	24.	64.	1926
0.2	24.8	33.	35.	68.	342
0.2	37.0	64.	65.	129.	284
Trace	12.8	21.	9.	30.	234
0.5	7.2	14.	13.	27.	257
0.3	17.0	34.	30.	64.	675
None	13.4	38.	39.	77.	197
Trace	9.7	.....	57.	57.	189
0.3	25.8	—26.	141.	115.	306
0.2	36.8	61.	77.	138.	266
Trace	14.4	4.	63.	67.	161
0.5	7.1	—28.	61.	33.	156
0.2	17.9	8.	73.	81.	212
Trace	10.9	24.	44.	68.	420
"	11.0	39.	.....	39.	717
"	34.6	36.	57.	93.	478
0.8	28.0	52.	.....	52.	295
0.4	24.8	36.	.....	36.	542
0.4	24.5	45.	.....	45.	203
1.1	21.7	27.	.....	27.	530
0.4	22.2	37.	.....	37.	455
Trace	11.4	35.	21.	56.	154
"	10.1	38.	.....	38.	149
0.8	17.5	43.	46.	89.	173
0.4	19.3	52.	.....	52.	171
Trace	20.2	43.	.....	43.	150
0.4	20.0	46.	.....	46.	158
1.3	20.0	45.	.....	45.	160
0.4	16.9	46.	.....	46.	159

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
OHIO RIVER. ¹ Filtered supplies—Concluded.					
Ripley, river.....	May 17	.30	237	Considerable	Earthy
“ “	Aug. 5	.25	42	Very slight	Faint vegetative
“ “	Sept. 17	.32	92	Decided	Vegetative
Average.....		.29	124		
OLENTANGY RIVER. Samples collected in 1897.					
Galion, above town.....	July 15	.4	Marked	Marked	Musty
“ “ “	Aug. 24	.3	None	Distinct	“
“ “ “	Sept. 24	.3	Clear	“	“
“ “ “	Oct. 22	.3	“	“	“
“ “ “	Nov. 30	.5	Distinct	Slight	“
Average.....					
Galion, below town.....	July 15	.4	Distinct	Distinct	Sour musty
“ “ “	Aug. 24	.2	None	Slight	“ “
“ “ “	Sept. 24	.35	“	“	“ “
“ “ “	Oct. 22	.5	Marked	Marked	Offensive
“ “ “	Nov. 30	.4	Distinct	Distinct	Mouldy
Average.....					
Delaware, above town.....	June 10	.2	Slight	Slight	Faint musty
“ “ “	July 15	.5	Strong	Marked	Musty
“ “ “	Aug. 24	.2	Slight	Distinct	None
“ “ “	Sept. 24	.2	“	Slight	Slight musty
“ “ “	Oct. 26	.2	Clear	Very slight	Very slight, earthy
“ “ “	Dec. 2	.8	Marked	Slight	Musty
Average.....					
Delaware, below town.....	June 10	.25	Very slight	Very slight	Faint musty
“ “ “	July 15	.5	Strong	Marked	Musty
“ “ “	Aug. 24	.25	Slight	Distinct	Very slight musty
“ “ “	Sept. 24	.2	Very slight	Slight	Musty
“ “ “	Oct. 26	.25	“	Very slight	“
“ “ “	Dec. 2	.6	Marked	Slight	“
Average.....					

¹The significance of the letters used in the turbidity column of the Ohio River results is as follows: Turbidity obtained by diluting river water with clear water, c = ratio of 1 volume of river water to 3 volumes of clear water; d = 1 to 4; e = 1 to 5; f = 1 to 6; h = 1 to 8; l = 1 to 12; r = 1 to 18. The letter u in a column means undetermined. Turbidities are in terms of silica standard.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
Trace	9.5	37.	34.	71.	526
"	15.5	49.	52.	101.	178
None	12.3	41.	32.	73.	165
...	12.4	42.	40.	82.	290
0.3	4.0	170.	26.	196.	355
0.0	9.5	230.	50.	280.	440
0.0	13.8	278.	42.	320.	525
0.1	11.5	248.	112.	360.	625
13.7	2.7	102.	115.	217.	372
2.8	8.3	206.	69.	275.	463
3.0	50.5	222.	.....	.....	805
0.1	43.5	320.	.....	.....	1080
0.0	67.5	272.	.....	.....	950
0.1	58.0	336.	126.	462.	825
11.1	34.0	158.	255.	413.	703
2.8	50.7	262.	190.	452.	873
0.5	3.5	204.	16.	220.	355
0.5	2.0	164.	22.	186.	350
0.1	2.0	202.	44.	246.	385
0.0	2.0	202.	66.	268.	435
Trace	3.0	226.	120.	346.	550
21.7	2.3	120.	96.	216.	376
3.8	2.5	186.	61.	247.	408
0.9	4.7	202.	28.	230.	355
2.8	4.0	152.	30.	182.	330
0.8	7.7	206.	62.	268.	405
0.5	15.7	236.	80.	316.	515
0.4	51.5	260.	142.	402.	710
15.9	3.3	122.	102.	224.	374
3.6	14.5	196.	74.	270.	448

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
OLENTANGY RIVER—Continued					
Olentangy Park, above.....	July 16	.3	Distinct	Marked	Slightly earthy
“ “ “	Aug. 24	.25	Slight	Slight	None
“ “ “	Sept. 23	.3	Distinct	Marked	Faint earthy
“ “ “	Oct. 21	.2	“	Distinct	Slight “
“ “ “	Dec. 3	.5	Very marked	“	“ “
Average					
Columbus, Dublin Bridge....	June 13	.2	Slight	Decided	Slight earthy
“ “ “	July 17	.3	Marked	Marked	Very faint
“ “ “	Aug. 23	.2	None	Slight	Sour musty
“ “ “	Sept. 23	.2	“	Distinct	Slight musty
“ “ “	Oct. 21	.15	Slight	Slight	Sour musty
“ “ “	Dec. 3	1.0	Marked	Distinct	Slight earthy
Average.....					
OTTAWA RIVER. Samples collected in 1898.					
Lima, above town.....	July 21	.1	Very slight	Very slight	Slight musty
“ “ “	Aug. 24	.15	None	“ “	“ “
“ “ “	Sept. 26	.45	Decided	Slight	None
“ “ “	Oct. 24	.45	Slight	Very slight	“
“ “ “	Nov. 16	.52	Distinct	Considerable	Faint only
Average.....		.29			
Lima, below town.....	July 21	3.50	Decided	Much	Foul, oily
“ “ “	Aug. 24	4.00	“	“	Foul
“ “ “	Sept. 26	.8	“	“	“
“ “ “	Nov. 16	.32	Distinct	Considerable	Oily
Average.....		2.15			
ST. JOSEPH RIVER. Samples collected in 1898.					
Ft. Wayne, above town.....	Aug. 23	.25	Very slight	Very slight	None
“ “ “ “	Sept. 27	.25	“ “	“ “	“
“ “ “ “	Oct. 25	.55	Distinct	Slight	Woody
“ “ “ “	Nov. 16	.4	Decided	Considerable	“
Average.....		.36			
ST. MARYS RIVER. Samples collected in 1898.					
Ft. Wayne, above town.....	July 22	.1	None	Very slight	None
“ “ “ “	Aug. 23	.25	“	None	“
“ “ “ “	Sept. 27	.4	Distinct	Slight	“
“ “ “ “	Oct. 25	.4	“	Very Slight	Earthy
“ “ “ “	Nov. 16	.26	Decided	Considerable	Woody
Average.....		.28			

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl ⁻)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
1.1	3.0	178.	50.	228.	390
0.2	5.8	206.	74.	280.	450
0.0	10.2	204.	134.	338.	555
0.5	7.7	226.	122.	348.	620
21.7	3.0	126.	98.	224.	404
4.9	5.9	188.	96.	284.	484
0.9	5.5	202.	48.	250.	415
1.4	3.2	166.	44.	210.	360
0.1	5.4	194.	72.	266.	440
0.0	8.5	192.	110.	302.	525
0.0	8.7	218.	112.	330.	585
21.2	3.0	132.	96.	228.	387
3.9	5.7	184.	80.	264.	452
1.4	29.6	187.2	158.0	345.2	642
1.0	24.3	173.8	74.6	248.4	590
0.6	119.8	151.6	78.2	229.8	828
1.5	22.1	172.2	30.4	202.6	392
46.1	17.1	137.8	57.6	195.4	373
10.2	42.6	164.5	79.8	244.3	565
2.4	183.2	227.6	171.4	399.0	1265
11.1	196.7	383.0	94.4	477.4	1121
2.5	300.2	237.6	61.3	298.9	1224
44.3	35.0	140.0	57.4	197.4	457
15.1	178.8	247.0	96.1	343.1	1017
0.5	4.7	219.0	10.4	229.4	362
0.4	2.2	232.2	None	232.2	335
1.2	5.0	172.0	67.8	239.8	433
33.6	2.5	122.2	31.0	153.2	375
8.9	3.6	186.4	27.3	213.7	376
2.0	34.5	160.2	160.8	261.0	835
0.3	104.5	141.2	68.8	210.0	716
0.4	76.6	155.9	44.4	200.3	589
0.8	96.4	148.2	94.6	242.8	580
42.0	34.5	169.6	29.4	139.0	420
9.3	69.3	143.0	67.6	210.6	628

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
SANDUSKY RIVER. Samples collected in 1898.					
Crestline, above town.....	Oct. 10	.25	Distinct	Very slight	None
“ “ “	Nov. 9	.40	Decided	Considerable	Woody
Average.....		.32			
Crestline, below town.....	July 14	1.00	Distinct	Considerable	Foul
“ “ “	Aug. 9	.40	“	“	“
“ “ “	Sept. 19	.60	Decided	“	Very musty
“ “ “	Oct. 10	.30	Distinct	“	Foul
“ “ “	Nov. 9	.60	Decided	“	Foul, earthy
Average.....		.58			
Crestline, below town.....	July 14	.10	.....	Slight	Slight musty
Bucyrus, above town.....	July 14	.10	Slight	Slight	None
“ “ “	Aug. 9	.3	Distinct	“	Faint musty
“ “ “	Sept. 19	.25	Slight	“	None
“ “ “	Oct. 10	.42	Distinct	“	Faint musty
“ “ “	Nov. 10	.50	Decided	Considerable	Earthy
Average.....		.31			
Bucyrus, below town.....	July 14	2.00	Decided	Much	Very foul
“ “ “	Aug. 9	.3	Distinct	Slight	Very offensive.
“ “ “	Sept. 19	.3	Slight	Considerable	Sour
“ “ “	Oct. 10	.45	Distinct	Slight	Musty
“ “ “	Nov. 10	.5	Decided	Considerable	Earthy
Average.....		.71			
Upper Sandusky, above town.	July 14	.0	Slight	Slight	Woody
“ “ “ “	Aug. 9	.15	“	“	“
“ “ “ “	Sept. 19	.25	Very slight	“	None
“ “ “ “	Oct. 10	.42	Distinct	“	Woody
“ “ “ “	Nov. 9	.45	Decided	Considerable	Earthy
Average.....		.25			
Upper Sandusky, below town ¹	July 14	.1	Slight	Slight	Musty
“ “ “ “	Aug. 9	.18	“	“	Offensive
“ “ “ “	Sept. 19	.35	Very slight	“	Musty
“ “ “ “	Oct. 10	.4	Distinct	“	“
“ “ “ “	Nov. 9	.45	Decided	Considerable	Earthy
Average.....		.30			

¹Sample not taken below all local sewage pollution.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.84	8.6	183.1	46.4	229.5	478
1.46	1.2	39.0	11.4	50.4	332
1.15	4.9	111.0	28.9	139.9	405
35.10	198.8	308.4	7.7	316.1	877
1.02	63.5	225.4	128.2	353.6	748
27.50	24.3	152.2	93.5	245.7	623
13.04	83.1	327.8	35.6	363.4	675
2.03	7.4	63.9	27.4	91.3	625
15.08	75.4	215.5	58.5	274.0	710
1.42	12.7	146.4	51.7	198.1	467
1.15	11.8	172.4	10.4	182.8	402
0.27	17.7	113.8	82.0	195.8	372
1.02	16.2	150.9	42.4	193.3	384
0.80	12.0	172.1	28.4	200.5	326
1.86	3.7	60.0	None	60.0	491
1.02	12.3	133.8	32.6	166.4	395
12.2	63.2	171.6	160.0	331.6	580
0.71	24.2	137.4	53.4	190.8	373
1.33	14.2	169.0	35.3	204.3	379
5.90	16.4	176.6	42.6	219.2	568
1.46	4.5	55.5	None	55.5	348
4.30	24.5	142.0	58.3	200.3	450
1.24	11.5	133.4	124.2	257.6	528
0.22	24.6	144.4	83.6	228.0	419
0.97	4.0	138.2	71.8	210.0	429
0.35	16.6	158.6	64.4	223.0	367
1.28	6.7	121.1	38.4	159.5	321
0.84	12.7	139.1	76.5	215.6	413
1.42	13.8	155.2	134.7	289.9	777
0.66	28.4	147.6	88.8	236.4	501
1.11	10.1	151.8	99.5	251.3	482
1.06	12.8	174.7	55.4	230.1	423
1.20	7.1	113.5	35.0	148.5	310
1.11	14.4	148.6	82.7	231.3	499

TABLE XIX
Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
SANDUSKY RIVER—Concluded.					
Tiffin, above town.....	July 15	.1	Slight	Slight	Peculiar
“ “ “	Aug. 10	.55	Decided	“	Woody
“ “ “	Sept. 20	.35	Very slight	“	“
“ “ “	Oct. 11	.25	Distinct	“	“
“ “ “	Nov. 9	.5	Decided	Considerable	Earthy
Average.....		.35			
Tiffin, below town.....	July 15	.2	Slight	Slight	Bad, musty
“ “ “	Aug. 10	.65	Decided	“	Sour
“ “ “	Sept. 20	.35	Very slight	“	Sweetish
“ “ “	Oct. 11	.3	Distinct	“	Musty
“ “ “	Nov. 9	.5	Decided	Considerable	Earthy
Average.....		.4			
Fremont, above town.....	July 15	.15	Slight	Slight	None
“ “ “	Aug. 10	.55	Distinct	“	Slight musty
“ “ “	Sept. 20	.4	Slight	“	“ “
“ “ “	Oct. 12	.28	“	“	“ “
“ “ “	Nov. 11	.47	Decided	Considerable	Earthy
Average.....		.37			
Fremont, below town.....	July 15	.2	Slight	Slight	Faint musty
“ “ “	Aug. 10	.55	Distinct	“	Musty
“ “ “	Sept. 20	.4	Very slight	Very slight	Faint musty
“ “ “	Oct. 12	.3	Distinct	Slight	“ “
“ “ “	Nov. 11	.47	Decided	Considerable	Earthy
Average.....		.38			
Sandusky, crib.....	July 16	.05	Very slight	Very slight	Woody
“ “	Aug. 11	.1	Slight	“ “	None
“ “	Sept. 21	.1	None	Trace	“
“ “	Oct. 12	.1	Slight	Slight	“
“ “	Nov. 10	.05	Very slight	“	“
Average.....		.08			
SCIOTO RIVER. Samples collected in 1897.					
Kenton, above town.....	June 12	.4	Very slight	Marked	None
“ “ “	July 16	.4	Distinct	“	Earthy
“ “ “	Aug. 25	.2	Marked	Distinct	None
“ “ “	Sept. 25	.4	Distinct	Slight	Slight earthy
“ “ “	Oct. 23	.3	“	“	Sour musty
“ “ “	Dec. 1	.5	Marked	“	Musty
Average.....		.3			

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
1.11	103.5	170.4	96.3	266.7	712
0.27	15.2	71.6	56.4	128.0	340
0.84	32.8	160.6	86.8	247.4	495
0.66	150.1	186.6	76.2	262.8	734
1.02	20.3	126.8	24.0	150.8	461
0.80	64.4	143.2	67.9	211.1	548
1.64	99.8	173.2	99.2	272.4	677
0.49	21.3	80.8	106.8	187.6	331
0.62	38.3	159.8	9.8	250.6	451
1.06	147.5	183.5	85.2	268.7	667
1.02	10.5	143.6	27.6	171.2	437
0.97	63.5	148.2	82.1	230.3	513
0.88	99.2	125.0	20.2	145.2	595
0.27	53.6	92.0	41.6	133.6	493
0.71	33.1	126.4	61.2	187.6	468
1.64	60.1	191.1	69.2	260.3	479
1.11	15.4	134.6	36.4	171.0	601
0.93	52.3	133.8	45.7	179.5	527
1.60	102.5	133.2	26.1	159.3	577
0.30	61.0	100.2	112.2	212.4	410
0.70	37.5	125.2	76.9	202.1	414
2.00	64.5	191.5	55.4	246.9	368
1.00	22.1	148.0	35.0	183.0	522
1.10	57.5	139.6	61.1	200.7	458
0.40	10.8	89.8	47.5	137.3	232
0.30	13.6	95.4	45.8	141.2	265
0.20	8.9	100.6	36.2	136.8	221
0.20	11.2	105.8	36.6	142.4	264
0.50	4.7	106.8	36.0	142.8	206
0.40	9.8	99.7	40.4	140.1	238
6.6	2.0	21.0	22.6	43.6	73.0
1.9	1.0	23.2	.....	.....	80.5
0.0	2.5	23.4	13.0	36.4	62.5
0.0	3.8	22.6	12.2	34.8	67.0
0.0	3.3	25.2	11.2	36.4	60.5
41.6	1.5	10.4	51.0	61.4	107.5
8.4	2.3	210.	183.	393.	752

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
SCIOTO RIVER—Continued.					
Kenton, below town.....	June 12	.45	Very slight	Slight	Slight
“ “ “	July 16	.3	Distinct	Marked	Offensive
“ “ “	Aug. 25	.2	“	“	“
“ “ “	Sept. 25	.35	Slight	Distinct	Oily
“ “ “	Oct. 23	.3	Clear	Marked	Slight offensive
“ “ “	Dec. 1	.5	Distinct	Slight	Marked musty
Average.....					
Girls' Industrial Home, above	Oct. 7	.15	Clear	Slight	Very faint musty
“ “ “ “	Oct. 26	.25	Slight	“	Slight musty
“ “ “ “	Dec. 2	.5	Marked	“	Earthy
Average.....					
Girls Industrial Home, below	Oct. 7	.15	Clear	Slight	Faint musty
“ “ “ “	Oct. 26	.25	“	Very slight	Slight musty
“ “ “ “	Oct. 26	.20	“	“	Slight musty sour
“ “ “ “	Dec. 2	.5	Marked	Slight	Earthy
“ “ “ “	Dec. 2	.4	“	“	Slight musty
Average.....					
Wyandotte Grove.....	June 13	.2	Slight	Marked	Trace sweet
“ “	July 17	.3	Marked	“	Very faint
“ “	Aug. 23	.2	Slight	Slight	None
“ “	Sept. 23	.15	Very slight	Distinct	Slight earthy
“ “	Oct. 21	.2	Distinct	Slight	Earthy
“ “	Dec. 3	.5	Marked	Distinct	Slight earthy
Average.....					
Jones' Dam.....	June 13	.2	Slight	Marked	None
“ “	July 17	.3	Marked	“	Trace
“ “	Aug. 23	.2	Slight	Distinct	Slight sour
“ “	Sept. 23	.2	Very slight	Slight	Slight earthy
“ “	Oct. 21	.2	Distinct	“	Earthy
“ “	Dec. 3	.5	Marked	Distinct	Slight earthy
Average.....					
Columbus, Sandusky St. Brdg.	June 13	.2	Distinct	Distinct	None
“ “ “ “	July 17	.3	Marked	Marked	Faint musty
“ “ “ “	Aug. 23	.2	Very slight	Slight	Sour musty
“ “ “ “	Sept. 23	.2	“ “	Distinct	Slight musty
“ “ “ “	Oct. 21	.15	“ “	Slight	Slight offensive
“ “ “ “	Dec. 3	.6	Marked	Distinct	Slight earthy
Average.....					

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
7.1	4.0	214.	228.	442.	710
0.0	4.5	32.	...	...	720
0.0	6.5	232.	118.	350.	605
0.0	12.5	238.	114.	352.	645
0.0	18.0	258	114.	372.	650
41.6	2.0	118.	466.	584.	975
8.0	7.9	182.	173.	355.	718
0.0	8.7	170.	112.	282.	485
0.0	9.5	210.	108.	318.	530
23.5	2.0	144.	148.	292.	512
0.8	6.6	175.	123.	298.	509
Trace	10.3	170.	122.	292.	500
None	10.0	210.	110.	320.	525
None	11.0	210.	113.	323.	525
28.3	1.5	138.	148.	286.	492
26.6	1.7	140.	142.	282.	501
9.3	7.5	173.	126.	299.	507
1.3	4.0	194.	52	246.	445
0.7	5.5	182.	94.	276.	500
0.1	3.8	172.	88.	260.	440
0.1	7.8	176.	126.	302.	550
0.2	7.7	200.	140.	340.	585
27.9	1.5	146.	132.	278.	467
4.9	5.0	178.	105.	283.	498
1.5	4.5	194.	48.	242.	455
0.9	3.8	184.	104.	288.	510
0.4	4.1	178.	80.	258	450
0.0	7.3	176.	116.	292.	510
0.2	7.4	192.	124.	316.	545
28.8	1.7	140.	136.	276.	464
5.3	4.8	177.	101.	278.	489
1.4	7.0	190.	62.	252.	480
1.2	4.0	184.	92.	276.	480
0.3	10.1	180.	78.	258.	445
0.0	11.5	152.	106.	258.	460
0.2	8.7	158.	98.	256.	525
25.7	2.3	144.	136.	280.	474
4.9	7.2	168.	95.	263.	477

TABLE XIX
Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
SCIOTO RIVER—Concluded.					
Columbus, Frank Rd. Bridge.	June 11	.2	Slight	Slight	Offensive
" " " "	July 17	.4	Distinct	Very marked	Offensive oily
" " " "	Aug. 23	.4	Very slight	Distinct	Offensive
" " " "	Sept. 23	.3	Distinct	Marked	Offensive musty
" " " "	Oct. 21	.5	Very marked	"	Very offensive
" " " "	Dec. 4	.4	Marked	"	Oily
Average.....					
Shadeville Bridge.....	July 17	.25	Very slight	Marked	Slight earthy
" "	Aug. 23	.3	" "	Slight	Slight sour
" "	Sept. 23	.3	Clear	Marked	Slight offensive
" "	Oct. 22	.5	Marked	Distinct	Offensive
" "	Dec. 4	.4	"	"	Musty
Average.....					
Circleville, above Darby Creek	June 14	.15	Clear	Decided	None
Circleville, Main St. Bridge..	July 22	1.0	Very turbid	Heavy	Slight earthy
" " " " ..	Aug. 26	.2	Slight	Distinct	.....
" " " " ..	Sept. 27	.15	"	Slight	Slight earthy
" " " " ..	Oct. 25	.25	Distinct	"	Slight musty
" " " " ..	Dec. 4	.5	Marked	"	Musty
Average.....					
Circleville, below town.....	June 14	.15	Clear	Decided	Slight sweet
Chillicothe, above.....	June 18	.15	None	Marked	Musty
LITTLE SCIOTO RIVER. Samples collected in 1897.					
Marion, above town.....	June 11	.3	Marked	Distinct	Faint musty
" " " "	July 15	.4	"	Marked	Slight
" " " "	Aug. 24	.3	Distinct	Distinct	Slight musty
" " " "	Sept. 24	.2	Very slight	Slight	Slight sour
" " " "	Oct. 23	.15	Slight	Distinct	Musty
" " " "	Dec. 1	.5	Marked	Slight	"
Average.....					
Marion, below town.....	June 11	.3	Distinct	Marked	Faint musty
" " " "	July 15	.3	Marked	"	Sour musty
" " " "	Aug. 24	.15	Clear	"	Sour
" " " "	Sept. 24	.2	Slight	Slight	Sour musty
" " " "	Oct. 23	.15	Clear	Marked	Offensive
" " " "	Dec. 1	.5	Marked	Slight	Musty
Average.....					

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.1	16.0	238.	86.	324.	495
0.0	13.0	182.	84.	266.	440
0.0	21.1	256.	94.	350.	520
0.0	39.0	330.	112.	442.	680
0.0	41.5	346.	92.	438.	765
19.5	6.0	160.	134.	294.	472
3.3	22.7	252.	100.	352.	562
0.9	14.5	226.	66.	292.	470
2.2	16.8	242.	70.	312.	475
0.0	28.5	314.	68.	382.	560
0.0	31.5	356.	52.	408.	605
23.9	5.3	152.	116.	268.	438
5.3	19.3	258.	74.	332.	510
1.9	6.5	244.	8.	252.	395
4.9	1.7	114.	54.	168.	285
0.7	5.5	228.	20.	248.	395
Trace	11.7	242.	28.	270.	400
0.5	11.2	282.	28.	310.	435
12.0	2.5	144.	76.	220.	393
3.6	6.5	202.	41.	243.	382
1.8	6.5	240.	30.	270.	405
2.0	4.5	246.	24.	270.	390
1.3	2.3	202.	56.	258.	430
1.6	1.0	180.	44.	224.	430
0.0	2.3	204.	58.	262.	470
0.0	16.5	258.	106.	364.	570
0.0	8.7	284.	68.	352.	545
30.1	1.0	94.	118.	212.	367
5.3	5.3	204.	75.	279.	469
1.9	6.5	208.	46.	254.	485
1.5	10.3	198.	54.	252.	485
0.1	25.5	276.	88.	364.	645
0.0	35.0	280.	122.	402.	675
0.0	19.5	308.	94.	402.	640
31.0	2.3	118.	108.	226.	392
5.8	16.5	231.	85.	316.	553

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
BIG STILLWATER CREEK. Samples collected in 1899.					
Uhrichsville and Dennison, above town.....	May 6	.20	.30	Slight	None
" " ".....	May 31	.30	1.50	Considerable	Musty
" " ".....	June 29	.25	.81	"	Faint musty
" " ".....	July 20	.23	.97	Much	Earthy, vegetative
" " ".....	Aug. 19	.35	.23	Slight	Old tea
" " ".....	Sept. 20	.22	.05	"	Earthy
" " ".....	Oct. 10	.18	.06	Very slight	None
" " ".....	Nov. 14	.25	.11	Slight	Faint sour
Average.....		.25	.50		
Uhrichsville and Dennison, below town.....	May 6	.22	.30	Slight	None
" " ".....	May 31	.30	1.46	Considerable	Musty
" " ".....	June 29	.30	.85	"	Earthy
" " ".....	July 20	.23	.53	Much	Earthy, vegetative
" " ".....	Aug. 19	.35	.17	Slight	" "
" " ".....	Sept. 20	.22	.13	Considerable	Musty
" " ".....	Oct. 10	.20	.08	Slight	Sour
" " ".....	Nov. 14	.20	.12	"	Faint musty
Average.....		.25	.46		
TUSCARAWAS RIVER.* Samples collected in 1899.					
Massillon, above town.....	May 5	.30	.07 ¹	Slight	Faint earthy
" " ".....	May 30	.22	.66	Considerable	Earthy
" " ".....	June 28	.20	.11 ¹	Very slight	Faint vegetative
" " ".....	July 19	.20	.06 ¹	" "	Vegetative
" " ".....	Aug. 18	.30	.06	" "	"
" " ".....	Sept. 19	.24	.08	Slight	Faint musty
" " ".....	Oct. 11	.10	.04 ¹	Very slight	Slight vegetative
" " ".....	Nov. 15	.30	.09	Slight	Vegetative
Average.....		.23	.15		
Massillon, below town.....	May 5	.30	.14	Slight	Musty
" " ".....	May 30	.22	.68	Considerable	Earthy
" " ".....	June 28	.25	.09	"	Strong musty
" " ".....	July 19	.30	.12	Slight	Mouldy
" " ".....	Aug. 18	.35	.09	"	Strong musty
" " ".....	Sept. 19	.30	.42	Considerable	Musty
" " ".....	Oct. 11	.30	.09	"	"
" " ".....	Nov. 15	.30	.11	Slight	Vegetative and faint musty
Average.....		.29	.22		

¹Stream was so shallow at the point of measurement that the turbidity rod rested on the bottom with the wire still visible.

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.1	1.2	112.0	None	112.0	271
0.5	7.2	47.1	36.4	83.5	735
0.5	3.8	98.4	14.0	112.4	324
0.2	1.4	92.0	5.2	97.2	386
0.3	4.0	125.0	29.0	154.0	235
0.4	5.8	163.8	6.4	170.2	274
0.1	8.1	140.6	22.2	162.8	249
0.2	4.4	134.2	29.4	163.6	278
0.3	4.5	114.1	17.8	131.9	344
Trace	2.3	95.2	22.4	117.6	278
4.0	7.4	40.4	6.3	46.7	753
0.7	6.6	59.5	26.6	86.1	332
0.3	2.5	93.0	55.8	148.8	316
0.2	5.6	114.2	19.4	133.6	231
0.3	12.8	111.2	98.2	209.4	378
0.2	12.4	160.4	42.4	202.8	318
0.2	7.2	116.6	50.2	166.8	399
0.7	7.1	98.8	40.2	139.0	376
0.2	60.7	130.6	30.7	161.3	440
0.8	28.0	72.9	3.4	76.3	425
0.1	126.0	150.5	6.6	157.1	574
0.4	160.3	128.2	94.0	222.2	629
0.0	76.8	154.8	74.4	229.2	365
0.0	194.1	154.4	115.0	269.4	687
Trace	77.3	160.0	62.6	222.6	482
0.5	99.2	143.4	77.6	221.0	505
0.3	102.8	136.8	58.8	195.6	513
0.1	32.2	136.6	43.0	179.6	356
0.8	23.3	70.5	5.7	76.2	395
0.5	81.5	162.4	5.8	168.2	455
0.5	137.6	148.8	56.8	205.6	609
C.C	43.0	178.6	39.8	218.4	1388
0.4	104.5	173.6	43.6	217.2	608
0.3	48.3	187.4	36.4	223.8	447
0.9	45.9	163.2	37.4	200.6	440
0.4	64.5	152.6	33.6	186.2	587

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
TUSCARAWAS RIVER—Concluded.					
Canal Dover, above town.....	May 5	.25	.27	Slight	Faint earthy
" " " ".....	May 31	.29	.85	Considerable	" musty
" " " ".....	June 29	.18	.40	Slight	Earthy
" " " ".....	July 20	.25	.35	"	"
" " " ".....	Aug. 21	.25	.22	"	Faint, musty
" " " ".....	Sept. 20	.15	.27	Considerable	Vegetative, earthy
" " " ".....	Oct. 11	.18	.13	Slight	Faint sour
" " " ".....	Nov. 15	.28	.11	"	Musty
Average.....		.23	.32		
New Philadelphia, below town.	May 5	.20	.27	Slight	Faint earthy
" " " ".....	May 31	.30	.88	Considerable	Faint musty
" " " ".....	June 29	.18	.37	Slight	Earthy
" " " ".....	July 20	.25	.29	"	Earthy, vegetative
" " " ".....	Aug. 21	.25	.17	"	Faint musty
" " " ".....	Sept. 20	.25	.55	Considerable	Vegetative, earthy
" " " ".....	Oct. 11	.20	.10	Slight	None
" " " ".....	Nov. 15	.30	.09	"	Faint musty
Average.....		.24	.34		
Coshocton, above town.....	May 6	.18	.13	Slight	None
" " " ".....	May 25	.30	.26	"	"
" " " ".....	June 23	.15	.19	"	Faint vegetative
" " " ".....	July 24	.14	.12	"	Faint tea
" " " ".....	Aug. 29	.15	.21	Considerable	Faint sour
" " " ".....	Sept. 26	.10	.16	Slight	Earthy
" " " ".....	Oct. 10	.15	.13	Very slight	Old tea
" " " ".....	Nov. 14	.15	.06	" "	Earthy
Average.....		.16	.16		
WALHONDING RIVER. Samples collected in 1899.					
Coshocton, above town.....	May 6	.15	.09	Slight	None
" " " ".....	May 25	.30	.32	"	"
" " " ".....	June 23	.24	1.30	Considerable	Earthy
" " " ".....	July 24	.23	.19	"	Faint vegetative
" " " ".....	Aug. 29	.22	.15	Slight	Faint sour
" " " ".....	Sept. 26	.25	.44	Considerable	Earthy
" " " ".....	Oct. 10	.15	.17	Slight	Faint sour
" " " ".....	Nov. 14	.15	.08	Very slight	Slightly vegetative
Average.....		.21	.34		

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.2	14.9	112.0	56.1	168.1	279
0.4	3.8	42.0	7.7	49.7	405
0.5	26.8	82.8	38.8	121.6	305
0.3	33.6	96.6	44.6	141.2	331
0.3	27.8	147.6	39.8	187.4	506
0.3	29.6	135.2	38.0	173.2	357
0.1	31.6	147.6	46.4	194.	394
0.3	22.8	138.4	42.8	181.2	372
0.3	23.8	112.8	39.3	152.1	369
0.3	13.8	101.4	10.8	112.2	288
0.4	4.8	36.8	9.1	45.9	432
0.5	19.6	80.	11.4	91.4	256
0.5	34.0	92.6	31.6	124.2	305
1.2	28.0	147.4	80.2	227.6	338
0.4	28.5	126.8	33.0	159.8	396
0.2	27.3	139.4	43.6	183.0	332
0.2	31.3	135.0	63.8	198.8	399
0.3	23.4	107.4	36.2	143.6	343
Trace	8.1	109.6	9.7	110.3	265
0.3	6.5	77.7	5.2	82.9	248
0.5	18.0	111.3	20.2	131.5	298
0.4	16.6	116.2	30.2	146.4	277
0.0	15.3	141.0	42.8	183.8	322
0.1	27.3	129.8	59.4	189.2	332
0.1	33.8	145.6	40.8	186.4	370
0.3	16.3	129.6	24.8	154.4	313
0.2	20.6	119.0	29.1	148.1	303
0.1	1.9	138.6	2.5	141.1	214
0.4	2.6	123.6	4.8	128.4	316
0.2	2.4	65.2	11.4	76.6	493
0.3	5.4	157.8	37.4	195.2	274
2.3	9.9	148.0	19.8	167.8	263
0.2	6.2	140.2	5.4	145.6	324
0.2	8.3	174.0	11.4	185.4	293
0.1	6.3	164.6	22.2	186.8	246
0.5	5.4	139.0	14.4	153.4	303

TABLE XIX

Descriptions and Chemical Analyses (parts per million)

Locality of Sample	Date collected	Color	Turbidity	Sediment	Odor
WILLS CREEK. Samples collected in 1899.					
Cambridge, above town.....	April 29	.05	.55	Slight	None
" " "	May 24	.25	.47	Considerable	Earthy
" " "	June 22	.22	2.90	"	Vegetative, earthy
" " "	July 24	.30	.45	"	Faint, earthy
" " "	Aug. 29	.15	.21	Slight	Vegetative
" " "	Sept. 26	.30	.55	Considerable	Slight vegetative, sour
" " "	Oct. 16	.35	.27	"	Sour
" " "	Nov. 21	.25	.27	Slight	Earthy
Average.....		.23	.71		
Cambridge, below town.....	April 29	.15	.18	Slight	Faint musty
" " "	May 24	.22	.32	Considerable	Musty
" " "	June 22	.27	2.40	"	Faint musty
" " "	July 24	.40	.32	"	Earthy
" " "	Aug. 29	.15	.30	"	Sour
" " "	Sept. 26	.25	.28	"	Woody
" " "	Oct. 16	.30	.11	Slight	Sour, musty
" " "	Nov. 21	.15	.25	Very slight	Earthy
Average.....		.24	.52		

SURFACE WATERS OF OHIO—Continued

Nitrate Ion (NO ₃)	Chloride Ion (Cl)	Carbonate or temporary hardness (CaCO ₃)	Non-carbonate or permanent hardness (CaCO ₃)	Total hardness	Total solids
0.6	165.4	137.2	88.7	225.9	786
0.4	4.5	143.2	42.8	186.0	354
0.4	5.0	83.0	1.6	84.6	968
1.9	4.5	118.6	20.0	138.6	301
0.2	8.3	152.6	43.6	196.2	348
0.3	7.3	112.4	81.0	193.4	317
0.1	12.2	176.4	16.4	192.8	391
0.1	7.2	170.8	31.6	202.4	328
0.5	26.6	136.8	40.7	177.5	474
0.7	5.6	125.9	52.3	178.2	336
0.6	5.3	102.6	20.4	123.0	279
0.4	6.6	89.0	18.4	107.4	442
2.7	13.0	80.4	77.8	158.2	298
0.4	12.1	29.4	151.4	180.8	404
0.2	14.7	28.8	134.6	163.4	335
0.0	13.9	137.2	40.8	178.0	376
0.1	9.0	146.8	29.2	176.0	344
0.6	10.0	92.5	65.6	158.1	352

PART III

THE CHEMICAL CHARACTER OF THE GROUND WATERS OF OHIO¹

The analyses of Part III were made under the author's direction in his laboratory at the Ohio State University. The collection of the samples of water and the actual details of the laboratory work were done by the assistant chemist at that time, Mr. C. R. DeLong, and it is a pleasure to record here the Survey's appreciation of his faithful and efficient services.

The analyses are mostly of ground waters though many surface supplies are included. In conformity with present day custom the results are given in parts per million of the constituent ions. (See Chapter III.)

It has not been forgotten, however, that many of those who may use these results are of the older school, and accordingly the results are also given in grains per U. S. gallon, and in addition to the ionic form of statement, the total and the carbonate (temporary) and non-carbonate (permanent) hardness are also given.

The descriptive matter accompanying the analytical results was obtained from the owner of the well or from the engineer who was using the water. No responsibility is assumed for the accuracy of the data about the wells nor for the accounts of the behavior of the water in boilers, etc. These observations are likely to be inaccurate in many cases because they were made by untrained observers; nevertheless it was deemed worth while to record what was offered by those who were using the water. A general interpretation of any of the analyses can be obtained from a study of the earlier chapters of this Bulletin.

¹Though this Bulletin is from the Geological Survey, it contains nothing concerning the geological features associated with the water supplies described. The reason for this omission lies in the fact that two rather extensive sources of information on these points are already at hand, namely: (1) "The Rock Waters and Flowing Wells of Ohio", by Edward Orton, in the Report of the Ohio State Board of Health for 1898. This paper is part of an investigation made in 1897-1898 and published under the title "Preliminary Report of an Investigation of Rivers and Deep Ground Waters as Sources of Public Water Supplies." (2) "The Underground Waters of Southwestern Ohio," by M. L. Fuller and F. G. Clapp, with a "Discussion of the Chemical Character of the Waters," by R. B. Dole. This is Water Supply Paper No. 259 of the United States Geological Survey.

No great claim of accuracy is made for the analyses. Some of the determinations are admittedly approximations only, for example those of sodium and silica and also those of the nitrate ion, in many cases at least, because no correction for the presence of chlorides was applied. It would be expected, therefore, that Stabler's test (55) would show many large errors of closure. A number of the analyses were tried by the Stabler formula and withstood the test very well, but only a small percentage of the total number were so tested. The laboratory work was faithfully watched throughout the progress of the work and therefore it is believed that a true picture of the Ohio ground waters is presented.

In the tabulations of results the so-called carbonate or temporary hardness has been corrected for normal carbonates and hydroxides where such values appear. The true alkalinity of such waters is therefore the so-called carbonate hardness plus the normal carbonates and hydroxides present.

Determinations of alkaline carbonates were not always made but such situations are suggested by the fact that the carbonate hardness is larger than the total hardness. (See paragraph 165 in Part I for a discussion of this.)

TABLE XX

GROUND WATERS OF OHIO
Descriptions and Chemical Analyses

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness CaCO ₃
AKRON						
Samples collected May 24-26, 1915.						
1	Quaker Oats Co., Howard and Mill Sts. Water from race from Blue Pond, Fritz, and Springfield Lakes. Used in condensers, for flushing and in boilers. Before going into boiler water is filtered and passed through a closed heater. Caused much scale. After using graphite old scale loosened, boilers now reported practically clean.	Pts. per mill.	266	172	145	27
		Grs. per gal.	15.5	10.0	8.5	1.6
2	Wellman, Seaver & Morgan Co., Ira Ave. Well, 135 ft., 4-inch casing, not in rock.	Pts. per mill.	300	82	195	None
		Grs. per gal.	17.5	4.8	11.4	
3	Same location as 2. Water from cistern in swamp. Used in Erie City and B. & W. water tube boilers. Use half bushel potatoes in boilers every three weeks. No boiler trouble now experienced. Had scale before using potatoes.	Pts. per mill.	406	177	130	47
		Grs. per gal.	23.7	10.3	7.6	2.7
4	Firestone Tire & Rubber Co., S. Main St. Three drilled wells, 100 ft. in shale. Pump 400 gal. per minute. Used for drinking.	Pts. per mill.	710	372	192	180
		Grs. per gal.	41.4	21.7	11.2	10.5
5	Same location as 4. Water from Summit Lake. Softened by We-fu-go softener. No boiler troubles.	Pts. per mill.	366	170	132	38
		Grs. per gal.	21.4	9.9	7.7	2.2
6	Miller Rubber Co., S. High St. Three wells, dug, 26 ft., 8 ft. in diameter, walled with brick. Give 500 gal. per minute. Softened in American softener with lime and soda ash. Water caused hard scale before softener was installed.	Pts. per mill.	692	437	255	182
		Grs. per gal.	40.4	25.5	14.9	10.6
6A	Water No. 6 above, after softening.	Pts. per mill.	502	132	(¹)	132
		Grs. per gal.	29.3	7.7	....	7.7

¹Normal carbonate = 122 pts. per mill. or 7.1 grs. per gal.
Hydroxide = 30 pts. per mill. or 1.8 grs. per gal.

TABLE XX
GROUND WATERS OF OHIO

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
15	45	10	2.2	177	12	1.0	14.8	20	14	1
0.88	2.6	0.58	0.13	10.4	0.70	0.06	0.87	1.2	0.82	
8.5	19	81	0.6	238	34	None	Very little	18	3	2
0.50	1.1	4.7	0.04	13.9	2.0			1.1	0.18	
12.2	51	55	3.0	159	72	1.5	50	12	8	3
0.71	3.0	3.2	0.18	9.3	4.2	0.09	2.9	0.70	0.47	
29	101	50	7.4	234	72	0.5	143	20	4	4
1.7	5.9	2.9	0.43	13.7	4.2	0.03	8.3	1.2	0.23	
12.2	48	52	0.7	161	70	1.0	41	6	6	5
0.71	2.8	3.0	0.04	9.4	4.1	0.06	2.4	0.35	0.35	
32	123	49	1.4	311	58	1.3	156	18	14	6
1.9	7.2	2.9	0.08	18.2	3.4	0.08	9.1	1.1	0.82	
3.6	47	124	0.3	....	64	3.0	118	20	None	6A
0.21	2.7	7.2	0.02	....	3.7	0.18	6.9	1.2		

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
AKRON—Continued						
7	Star Rubber Co., Switzer Ave. Drilled well, 80 ft., 8-inch, in shale. Used in boilers with boiler compound but still have scale trouble.	Pts. per mill.	764	450	227	223
		Grs. per gal.	44.6	26.3	13.2	13.0
8	Akron Foundry Co., 526 Washington St. Spring, formerly at surface but now 8 ft. below as result of fill. Used in boiler with closed type feed water heater. No boiler trouble.	Pts. per mill.	708	272	50	222
		Grs. per gal.	41.3	15.9	2.9	12.9
9	Goodrich Tire & Rubber Co., S. Main St. Drilled well, 150 ft., 8-inch casing, through gravel, sandstone, clay, and sand. Used for cooling.	Pts. per mill.	748	337	82	255
		Grs. per gal.	43.6	19.7	4.8	14.9
10	Same location as 9. Water from Ohio and Erie Canal. Used with Red Star boiler compound in Sterling water tube boilers. Hard scale formed before compound was used. Scale now is soft.	Pts. per mill.	356	162	127	35
		Grs. per gal.	20.8	9.4	7.4	2.0
11	Klages Coal & Ice Co., 557 S. High St. Dug well, 31 ft. in quicksand and gravel.	Pts. per mill.	1056	680	335	345
		Grs. per gal.	61.5	39.7	19.6	20.1
12	International Harvester Co., E. Center St. Three wells, 100 feet, 6-in. casing, to rock, end in rock. Pump 25 gal. per minute.	Pts. per mill.	614	255	67	188
		Grs. per gal.	35.8	14.9	3.9	11.0
13	Goodyear Tire & Rubber Co., E. Market St. Water from race fed by Fritz and Springfield Lakes. Used in Sterling water tube boilers with open heater. Hard scale $\frac{1}{8}$ in. thick forms in a month.	Pts. per mill.	288	172	140	32
		Grs. per gal.	16.8	10.0	8.2	1.9
14	Same location as 13. Well, 60 ft., 6-in. casing, pumps 600 gal. per minute. Used for drinking.	Pts. per mill.	558	342	177	165
		Grs. per gal.	32.5	19.9	10.3	9.6
15	Renner Brewing Co., 279 Forge St. Spring with cistern around it. Used in brewing.	Pts. per mill.	852	240	75	165
		Grs. per gal.	49.7	14.0	4.4	9.6

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
33	126	42	3.6	277	68	0.25	165	26	30	7
1.9	7.4	2.5	0.21	16.1	4.0	0.02	9.6	1.5	1.8	
23	71	58	0.5	61	96	50	106	22	52	8
1.3	4.1	3.4	0.03	3.5	5.6	2.9	6.2	1.3	3.0	
28	89	76	5	100	106	19	186	22	28	9
1.6	5.2	4.4	0.29	5.9	6.2	1.1	10.9	1.3	1.6	
12.2	45	51	1.6	155	72	0.5	43	16	6	10
0.71	2.6	3.0	0.09	9.0	4.2	0.03	2.5	0.93	0.35	
45	198	107	1.2	409	152	7.0	256	38	63	11
2.6	11.5	6.2	0.07	23.9	8.9	0.41	14.9	2.2	3.7	
23	64	68	0.2	82	88	33	132	18	32	12
1.3	3.7	4.0	0.01	4.8	5.1	1.9	7.7	1.1	1.9	
27	25	15	1.0	171	8	2.5	36	66	3	13
1.6	1.5	0.88	0.06	10.0	0.47	0.15	2.1	3.9	0.18	
24	97	25	0.6	216	34	4.5	140	34	24	14
1.4	5.7	1.5	0.04	12.6	2.0	0.26	8.2	2.0	1.4	
17	68	155	0.2	91	240	20	105	60	21	15
0.99	4.0	9.0	0.01	5.4	14.0	1.2	6.1	3.5	1.2	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
AKRON—Concluded						
16	Ohio Building, Main and Church Sts. Drilled well, 114 feet, 8-in. casing, in rock with shale at bottom. Used in boilers.	Pts. per mill.	960	437	95	342
		Grs. per gal.	56.0	25.5	5.5	19.9
17	The M. O'Neil Co., Main St. Drilled well, 111 ft., 8-in. casing, ending in sand. Pumps 50 gal. per minute. Used for drinking.	Pts. per mill.	816	460	262	198
		Grs. per gal.	47.6	26.8	15.3	11.5
ALLIANCE						
Samples collected Oct. 7-8, 1915.						
18	City Water Works, Walnut Ave. Water from Mahoning River treated with alum as coagulant and filtered through rapid sand filter. Used in boilers gives hard scale, but with Hawkeye boiler compound scale is kept soft.	Pts. per mill.	280	196	112	84
		Grs. per gal.	16.3	11.4	6.5	4.9
19	Same location as 18. Raw water from Mahoning River.	Pts. per mill.	310	204	127	77
		Grs. per gal.	18.1	11.9	7.4	4.5
20	Alliance Cold Storage & Packing Co., Prospect and Linden Sts. Drilled well, 147 ft. Used in boilers with soda ash. Open feed water heater also used. Some scale still forms.	Pts. per mill.	528	388	372	16
		Grs. per gal.	30.8	22.6	21.7	0.93
21	Alliance Machine Co., Mahoning Ave. Drilled well, 309 ft., 6-in. casing to rock. Used for drinking. Behaves about like city water in boilers.	Pts. per mill.	1042	22	505	None
		Grs. per gal.	60.8	1.3	29.4	
22	Alliance Ice & Coal Co., S. Mahoning Ave. Drilled well, 250 ft., 4-in. casing to rock. Used in boilers. Forms very little scale. Open feed water heater removes considerable scale.	Pts. per mill.	630	113	400 ²	None
		Grs. per gal.	36.8	6.6	23.3	

²Normal carbonate = 15 pts. per mill. or 0.88 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
32	123	71	0.3	116	98	27.5	205	34	56	16
1.9	7.2	4.1	0.02	6.7	5.7	1.6	12.0	2.0	3.3	
33	130	32	2.6	320	74	0.25	110	58	11	17
1.9	7.6	1.9	0.15	18.7	4.3	0.02	6.4	3.4	0.64	
15	54	8	0.3	137	10	1.0	84	10	8	18
0.88	3.2	0.47	0.02	7.9	0.58	0.06	4.9	0.58	0.47	
16	56	10	1.8	155	10	1.7	82	24	9	19
0.93	3.3	0.58	0.11	9.0	0.58	0.10	4.8	1.4	0.53	
41	87	46	0.2	454	30	0.25	100	26	22	20
2.4	5.1	2.7	0.01	26.5	1.8	0.02	5.8	1.5	1.3	
1.2	6.8	394	2.2	616	260	None	None	16	7	21
0.07	0.40	23.0	0.13	35.9	15.2			0.93	0.41	
23	7.2	201	0.2	488	88	None	4	18	None	22
1.3	0.42	11.7	0.01	28.4	5.1		0.23	1.1		

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness CaCO ₃
ASHLAND						
Samples collected August 26, 1915.						
23	City Pumping Station, 1½ miles from city. Drilled well, 30 ft., 10-in. casing in gravel. Pumps 500,000 gal. per day. Was used for a while in boilers with soda ash. Not much scale reported.	Pts. per mill.	568	346	260	86
		Grs. per gal.	33.1	20.2	15.2	5.0
24	Same location as 23. Creek water. Used in boilers with sugar compound. Open feed water heater employed. Not much scale reported but much mud in heater.	Pts. per mill.	416	248	195	53
		Grs. per gal.	24.3	14.5	11.4	3.1
25	Faultless Rubber Co., E. Fourth St. Well 82 ft., 8-in. casing. Rock at 8 ft. Water level 13 ft. from surface. Used in Erie City water tube boilers with feed water heater. Gives a soft sludge only.	Pts. per mill.	1084	282	217 ^a	65
		Grs. per gal.	63.2	16.4	12.6	3.8
26	Drs. Hess and Clark Laboratory, Orange St. and railroad. Drilled well, 126 ft., 6-in. casing, about 100 ft. to rock. Used in boilers with open feed water heater. Soda ash put into water. Gives a little hard scale. Heavy precipitate in heater.	Pts. per mill.	700	398	297	101
		Grs. per gal.	40.8	23.2	17.3	5.9
27	F. E. Myers & Bros., Orange St. Drilled well, 175 ft., 8- and 6-in. casings. Rock at 35 ft. Water level 24 ft. from surface. Composite sample with two other wells, 65 and 100 ft. Used in B. & W. boiler with open feed water heater. Soda ash mixed with water. Gives small amount of hard scale.	Pts. per mill.	986	510	367	143
		Grs. per gal.	57.4	29.8	21.4	8.3
28	Weber Ice Co., Cottage St. Well, 116 ft., 10-in. casing to bottom, rock all the way. Another well at plant, 150 ft. Water used in fire tube boilers. Not much scale. Graphite was tried but no effect observed.	Pts. per mill.	936	239	310	None
		Grs. per gal.	54.6	13.9	18.1	

^aNormal carbonate = 10 pts. per mill. or 0.58 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
27	94	32	1.0	317	46	None	91	18	20	23
1.6	5.5	1.9	0.06	18.5	2.7		5.3	1.1	1.2	
18	69	21	3.6	238	6	0.8	70	62	5	24
1.1	4.0	1.2	0.21	13.9	0.35	0.05	4.1	3.6	0.29	
22	77	299	1.0	265	410	4.5	97	30	None	25
1.3	4.5	17.4	0.06	15.4	23.9	0.26	5.7	1.8		
38	97	80	0.4	362	70	5	129	22	49	26
2.2	5.7	4.7	0.02	21.1	4.1	0.29	7.6	1.3	2.9	
46	128	123	2.0	448	124	3.0	171	36	56	27
2.7	7.5	7.2	0.12	26.1	7.3	0.18	9.9	2.1	3.3	
23	58	258	0.5	378	250	3.0	120	24	29	28
1.3	3.4	15.0	0.03	22.1	14.6	0.17	7.0	1.4	1.7	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
ASHTABULA						
Samples collected October 2, 1915.						
29	City Water Works. Lake Erie water taken at point 3 miles from shore. Alum used as coagulant, water then filtered through sand. Used in boilers with Hawkeye compound. Some soft scale is formed. Harder scale without use of compound. Closed heater employed; not much sediment in it.	Pts. per mill. Grs. per gal.	150 8.8	113 6.6	95 5.5	18 1.1
30	Same location as 29. Lake Erie water, 2,900 ft. from shore.	Pts. per mill. Grs. per gal.	162 9.4	150 8.8	100 5.8	50 2.9
31	R. W. Griswold, Woodman Ave. Eight dug wells, 12 ft., 8 to 4 ft. in diameter, walled with brick. Used in boilers gives scale trouble. Compound employed did not help much.	Pts. per mill. Grs. per gal.	1018 59.4	445 26.0	115 6.7	330 19.3
	Fargo Mineral Springs Co. Spring on the deep gulf about 100 ft. above the river and 30 ft. below top of bank.					
	No analysis was made but company reports that it has no trouble in any way with the water when used in boilers.					
ATHENS						
Samples collected January 25, 1916.						
32	City Water Works. Nine drilled wells, 126 ft., 6-, 8-, and 10-in. casings. These wells go through gravel to rock. Two wells, 40 ft., through gravel and ending in rock, 12-in. casing. All wells average 1,000,000 gal. per day. When used in boilers water gives much scale.	Pts. per mill. Grs. per gal.	438 25.5	309 18.0	195 11.4	114 6.6
33	Athens Ice & Storage Co. Drilled well, 128 ft., 6-in. casing, 28 ft. into rock. Salt water is struck at about 200 ft. Used in fire tube boiler with soda ash and graphite, forms no scale.	Pts. per mill. Grs. per gal.	722 42.1	455 26.5	237 13.8	218 12.8

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
9.7	29	2.9	0.36	116	8	None	15	14	5	29
0.57	1.7	0.17	0.02	6.7	0.47		0.88	0.82	0.29	
18	30	None	1.5	122	10	0.5	10	36	None	30
1.1	1.8		0.09	7.1	0.58	0.03	0.58	2.1		
37	116	90	1.8	140	74	75	260	28	53	31
2.2	6.8	5.3	0.11	8.2	4.3	4.4	15.2	1.6	3.1	
....
23	86	28	0.2	238	46	0.5	102	....	29	32
1.3	5.0	1.6	0.01	13.9	2.7	0.03	5.9	....	1.7	
30	132	45	0.4	289	98	4	141	....	28	33
1.8	7.7	2.6	0.02	16.8	5.7	0.23	8.2	....	1.6	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate ¹ or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
ATHENS—Concluded						
34	Athens State Hospital. Three drilled wells, 125 ft., 10-in. casings to rock struck at 110 ft. Each well on test pumped 900 gal. per minute. In very dry weather level of water goes down a little. "Water seemed harder when well was first drilled." When used in boilers gives much scale trouble. Eureka softener installed eliminated some scale.	Pts. per mill.	430	342	287	55
		Grs. per gal.	25.1	19.9	16.7	3.2
35	Water from 34 after softening. Sixty pounds of lime and 4 pounds soda ash were used per 140,000 gal.	Pts. per mill.	278	180	115 ⁴	65
		Grs. per gal.	16.1	10.5	6.7	3.8
BARBERTON						
Samples collected October 11, 1915.						
36	City Water Works, High St. Twelve driven wells in gravel, 90 ft. Water at 50 ft., 8-in. casings. 800,000 gal. pumped. When used in boilers gave much trouble from corrosion, pitted shell more than tubes.	Pts. per mill.	242	206	165	41
		Grs. per gal.	14.1	12.0	9.6	2.4
37	Diamond Match Co. Drilled well, 80 ft., 8-in. casing. First 20 ft. clay, then gravel and quicksand, ending in gravel. Used for drinking only.	Pts. per mill.	244	210	200	10
		Grs. per gal.	14.2	12.3	11.7	0.58
38	Same location as 37. Ohio Canal water. Used in water tube boilers with open feed water heater which is reported not to remove much scale. Graphite employed loosens scale.	Pts. per mill.	216	179	167	12
		Grs. per gal.	12.6	10.4	9.7	0.70
39	Columbia Chemical Co., Wooster Road. Water from Wolf Creek, water at average stage. This water is softened by Kennicott system using lime and soda ash. Gives no scale trouble.	Pts. per mill.	246	179	135 ⁵	44
		Grs. per gal.	14.4	10.4	7.9	2.6

¹Normal carbonate = 15 pts. per mill. or 0.88 grs. per gal.⁵Normal carbonate = 5 pts. per mill. or 0.29 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
24	97	24	0.8	350	28	0.5	56	....	34	34
1.4	5.7	1.4	0.05	20.4	1.6	0.03	3.3	....	2.0	
24	32	31	0.6	140	28	0.6	52	....	None	35
1.4	1.9	1.8	0.04	8.2	1.6	0.04	3.0	....	
16	56	None	0.9	201	8	None	47	10	4	36
0.93	3.3		0.05	11.7	0.47		2.7	0.58	0.23	
17	56	5	1.0	244	6	0.4	27	4	8	37
0.99	3.3	0.29	0.06	14.3	0.35	0.02	1.6	0.23	0.47	
13	50	1.0	0.4	204	8	0.7	42	None	5	38
0.76	2.9	0.06	0.02	11.8	0.47	0.04	2.5		0.29	
15	48	3	3.4	165	8	5.5	47	22	None	39
0.88	2.8	0.18	0.20	9.6	0.47	0.32	2.7	1.3		

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
BARBERTON—Concluded						
40	Pittsburgh Valve & Fittings Co., Newell St. Five wells, 80 ft., 8- to 10-in. casings, ending in gravel. Used in boilers with open heater. Boiler compound employed also.	Pts. per mill.	360	283	187	96
		Grs. per gal.	21.0	16.4	10.9	5.6
BELLEFONTAINE						
Samples collected July 29, 1915.						
41	City water supply, S. Main St. Seven drilled wells; two 75 ft. and five 180 to 260 ft., 8- to 12-in. casings. Pump 1,500,000 gal. per 24 hrs. Sample is from one of the 75-ft. wells ending in gravel.	Pts. per mill.	354	276	240	36
		Grs. per gal.	20.6	16.1	14.0	2.1
42	Same as 41. Drilled well 200 ft. Rock at 90 ft., 8-in. casing to rock. Water level 2 ft. from surface. Water from all wells used in boilers with feed water heater. Boiler compound used. Not much trouble from scale.	Pts. per mill.	418	323	322	1
		Grs. per gal.	24.4	18.8	18.8	0.06
43	Bellefontaine Bridge & Steel Co. One mile south of center of city. Drilled well, 96 ft., 5-in. casing ending in gravel. Water level 40 ft. from surface. Used for cooling. Tried in boilers but gave much hard scale. Boiler compound tried but without success.	Pts. per mill.	432	338	285	53
		Grs. per gal.	25.2	19.7	16.6	3.1
44	A. J. Miller & Co., South Elm St. and Big Four R. R. Driven well, 20 ft. in gravel. Pumps 3,000 gal. in 10 hrs. Used in boilers with "Metaline" compound. Keeps scale loose.	Pts. per mill.	868	558	372	186
		Grs. per gal.	50.6	32.5	21.7	10.9
45	Citizens Ice & Supply Co., N. Walker St. Two drilled wells, 103 and 170 ft., 17 ft. to rock. Water level 15 ft. from surface. Used in boilers with feed water heater. Soft sludge in boilers easily washed out. When boiler compound was used scale seemed to increase. Sample is from 103 ft. well.	Pts. per mill.	862	477	315	162
		Grs. per gal.	50.3	27.8	18.4	9.4

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
18	83	2	1.2	228	16	None	108	16	8	40
1.05	4.8	0.12	0.07	13.3	0.93		6.3	0.93	0.47	
32	58	20	0.6	293	8	None	65	28	7	41
1.9	3.4	1.2	0.04	17.1	0.47		3.8	1.6	0.41	
35	71	36	1.0	393	8	None	49	16	6	42
2.0	4.1	2.1	0.06	22.9	0.47		2.9	0.93	0.35	
37	73	28	2.4	348	8	None	68	12	11	43
2.2	4.3	1.6	0.14	20.3	0.47		4.0	0.70	0.64	
54	133	50	1.6	454	20	12	222	38	35	44
3.2	7.7	2.9	0.09	26.5	1.2	0.70	12.9	2.2	2.0	
50	109	58	1.3	384	34	19	196	36	32	45
2.9	6.4	3.4	0.08	22.4	2.0	1.1	11.4	2.1	1.9	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
BELLEFONTAINE—Concluded						
46	Big Four R. R. shops. Three drilled wells, 440 ft., 38 ft. to rock, 12-in. casings to rock. Used in boilers after softening with lime and soda ash.	Pts. per mill.	520	359	257	102
		Grs. per gal.	30.3	20.9	15.0	5.9
BOWLING GREEN						
	Home Steam Laundry, well 104 ft. and P. M. Davidson Ice Co. well 200 ft. Both report the waters hard.	.....	.....	.....	.....	.....
BUCYRUS						
	Toledo & Ohio Central R. R. Co. reports a well of 108 ft. with a capacity of about 1,000 gal. per hour. In a boiler the water causes scale and some foaming.	.....	.....	.....	.....	.....
	The Bucyrus Rubber Co. uses city water from reservoir and reports no boiler trouble when used with compound.	.....	.....	.....	.....	.....
	The Shunk Plow Co. uses Sandusky River water and reports pitting and scale.	.....	.....	.....	.....	.....
CADIZ						
	City water obtained from wells of 150 to 265 ft. in limestone. Each well can furnish from 75 to 100 gal. per minute. Two users report pitting and scale.	.....	.....	.....	.....	.....
CAMBRIDGE						
Samples collected November 10, 1915.						
47	City Water Works, Wills Creek. Water direct from creek which was at low stage; 1,500,000 gal. per 24 hrs. pumped. Creek is fed from mines but no trouble from acid reported. Used in boiler forms thin but hard scale. When creek is at low stage foaming is observed.	Pts. per mill.	530	223	205	18
		Grs. per gal.	30.9	13.0	12.0	1.1

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
45	70	27	0.6	313	20	2.3	106	62	2	46
2.6	4.1	1.6	0.04	18.3	1.2	0.13	6.2	3.6	0.12	
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13.4	67	98	0.6	250	82	None	102	16	8	47
0.78	3.9	5.7	0.04	14.6	4.8		6.0	0.93	0.47	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
CAMBRIDGE—Concluded						
48	American Sheet & Tin Plate Co. Water from Leatherwood Creek. Supply sufficient. Used in boilers after softening.	Pts. per mill.	526	237	127	110
		Grs. per gal.	30.7	13.8	7.4	6.4
49	Same location as 48. Water after softening. The treatment with lime and soda ash varies a good deal with the season. When the creek is low and contains many leaves there is trouble from foaming. Before softening system was installed much trouble from priming and foaming was experienced.	Pts. per mill.	420	54	(⁶)	54
		Grs. per gal.	24.5	3.2	.....	3.2
50	American Sheet & Tin Plate Co., N. Second St. Drilled well, 125 ft., 6-in. casing to sandstone at 25 ft. Used for drinking.	Pts. per mill.	768	485	225	260
		Grs. per gal.	44.8	28.3	13.1	15.1
51	Suite Bros. Manufacturing Co., Gamber Ave. Driven well, 128 ft., 5-in. casing. Used for drinking.	Pts. per mill.	504	7	380 ⁷	None
		Grs. per gal.	29.4	0.41	22.2	

CANAL DOVER

Samples collected November 12, 1915.

52	City Water Works, Park Ave. and Broadway. Twenty-four drilled wells, 45 to 200 ft., 6- and 8-in. casings to bottom, in gravel. 800,000 gal. per day pumped. Used in boilers with Franklin compound. Boilers were run 21 years without putting in new tubes. An open feed water heater removes some sludge.	Pts. per mill.	316	253	215	38
		Grs. per gal.	18.4	14.7	12.5	2.2
53	American Sheet & Tin Plate Co., Tuscarawas Ave. Eight wells, 80 ft., 8-in. casings to bottom. Water is softened with lime and soda ash by Scaife system. No trouble in boilers.	Pts. per mill.	274	226	195	31
		Grs. per gal.	16.0	13.2	11.3	1.8

⁶Normal carbonate = 55 pts. per mill. or 3.2 grs. per gal.
Hydroxide = 10 pts. per mill. or 0.58 grs. per gal.

⁷Normal carbonate = 10 pts. per mill. or 0.58 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
16	69	69	0.4	155	8	0.25	206	14	5	48
0.93	4.0	4.0	0.02	9.0	0.47	0.02	12.0	0.82	0.29	
6.1	11.6	112	0.1	....	10	None	210	16	None	49
0.36	0.68	6.5	0.01	....	0.58		12.3	0.93		
50	112	57	0.24	274	132	13	146	10	34	50
2.9	6.5	3.3	0.01	16.0	7.7	0.75	8.5	0.58	2.0	
1.2	0.8	188	0.4	464	16	None	5	12	None	51
0.07	0.05	11.0	0.02	27.1	0.93		0.29	0.7		
17	73	9	0.4	262	8	0.25	56	10	10	52
0.99	4.3	0.53	0.02	15.3	0.47	0.02	3.3	0.58	0.58	
18	60	6	0.3	238	8	0.25	42	14	7	53
1.1	3.5	0.35	0.02	13.8	0.47	0.02	2.5	0.82	0.41	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or tem- porary hardness, CaCO ₃	Non- carbonate or per- manent hardness, CaCO ₃
CANAL DOVER—Concluded						
54	Dover Manufacturing Co., River St. Dug well, 20 ft., walled with brick. Used in boilers gives much hard scale. After using Hawkeye compound scale is looser.	Pts. per mill.	474	322	187	135
		Grs. per gal.	27.6	18.8	10.9	7.9
55	Penn Iron & Coal Co. Well, 80 ft., 6-in. casing to bottom. Pumps 225,000 gal. per 24 hrs. Used in boilers after softening with lime and soda ash by Scaife system. No trouble from soft- ened water.	Pts. per mill.	386	276	175	101
		Grs. per gal.	22.5	16.1	10.2	5.9
CANTON						
Samples collected May 27-29, 1915.						
56	J. H. McClain, S. Cleveland Ave. and Pennsylvania R. R. Two drilled wells, 110 ft., 4-in. casings. Used in boilers with Dearborn compound. Much scale reported.	Pts. per mill.	640	355	225	130
		Grs. per gal.	37.3	20.7	13.1	7.6
57	Same location as 56. Well, 50 ft., 6-in. casing. Pumped 75 gal. per minute.	Pts. per mill.	822	515	305	210
		Grs. per gal.	48	30	17.8	12.2
58	Knight Tire & Rubber Co., S. Main St. and Pennsylvania R. R. Four driven wells, 50 ft., 6-in. casings, in sand. Used in boilers with Hoppes feed water heater. Arrow boiler compound also employed. Report boilers clean since using the compound.	Pts. per mill.	596	407	245	162
		Grs. per gal.	35	23.7	14.3	9.4
59	Timken Roller Bearing Co., Dueber and 20th St., S. W. Three driven wells, 34 ft. in gravel. Used in boilers with Arrow compound and soda ash. Can- not run two weeks without compound. Boilers washed out every two weeks.	Pts. per mill.	944	607	247	360
		Grs. per gal.	55	35.4	14.4	21

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
23	91	20	0.3	228	22	2.5	118	14	6	54
1.3	5.3	1.2	0.02	13.3	1.3	0.15	6.9	0.82	0.35	
20	78	10	0.1	214	14	12	92	14	6	55
1.2	4.6	0.58	0.01	12.4	0.82	0.70	5.4	0.82	0.35	
24	102	51	0.3	274	24	None	159	32	6	56
1.4	5.9	3.0	0.02	16.0	1.4		9.3	1.9	0.35	
34	150	36	0.2	372	42	4.5	162	36	27	57
2.0	8.8	2.1	0.01	21.7	2.5	2.6	9.4	2.1	1.6	
27	119	23	2.6	299	24	None	138	54	3	58
1.6	6.9	1.3	0.15	17.4	1.4		8.0	3.2	0.17	
37	181	59	0.4	301	24	6.0	279	62	68	59
2.2	10.6	3.4	0.02	17.6	1.4	0.35	16.2	3.6	4.0	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or tem- porary hardness, CaCO ₃	Non- carbonate or per- manent hardness, CaCO ₃
CANTON—Continued						
60	Cleveland Axle Co., Dueber and 20th St., S. W. Drilled well, 300 ft., 8-in. casing to rock at 100 ft. Pumps 180 gal. per minute, 10 hrs. per day. Used in boilers with Arrow compound and soda ash. Soft scale, washed out every two weeks, not much hard scale. Open heater also used. Removes 500 lbs. sludge in eight weeks.	Pts. per mill.	320	245	215	30
		Grs. per gal.	19	14.3	12.5	1.8
61	The Berger Manufacturing Co., Belden and 11th Sts., N. E. Two drilled wells, 325 ft., 6-in. casings to rock. Used in boilers with compounds from Parsons Chemical Co. and from Lords Chemical Co. Hard scale, sticks to tubes. Turbined every 4 to 6 weeks. Without compound turbinning every 2 weeks would be necessary. Open feed water heater used.	Pts. per mill.	420	255	222	33
		Grs. per gal.	24.5	14.8	13	1.9
62	Same location as 61. Two drilled wells, 70 ft. in gravel. Used in boilers. Trouble from corrosion reported. Foreman believed that acid from the plant found its way into wells.	Pts. per mill.	370	247	177	70
		Grs. per gal.	21.5	14.2	10.3	4.1
63	Diebold Safe & Lock Co., Mulberry Road. Driven well, 30 ft. in gravel. Used for drinking. City water in boilers.	Pts. per mill.	938	622	327	295
		Grs. per gal.	54.6	36.3	19.0	17.1
64	Canton Electric Co., 700 Second St., S. E. Well, driven 190 ft. to rock and drilled from there to total depth of 290 ft. Water level 45 ft. from surface. Pumps 45 gal. per minute for 24 hrs. Used in boilers with soda ash. Open feed water heater removes some scale. Return water used in boilers. No scale trouble.	Pts. per mill.	504	222	302	None
		Grs. per gal.	29.4	12.9	17.6	

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
20	66	15	1.1	262	8	0.5	41	46	12	60
1.2	3.9	0.87	0.06	15.3	0.46	0.03	2.4	2.7	0.7	
18	72	43	38	271	22	None	79	36	18	61
1.1	4.2	2.5	0.22	15.9	1.3		4.6	2.1	1.1	
18	69	18	0.4	216	8	5.5	77	38	5	62
1.1	4.0	1.1	0.02	12.6	0.46	0.32	4.5	2.2	0.29	
39	185	41	0.8	399	42	23	232	30	37	63
2.3	11.0	2.4	0.05	23.2	2.5	1.3	13.5	1.8	2.2	
21	55	97	1.1	368	36	None	83	36	8	64
1.2	3.2	5.7	0.06	21.5	2.1		4.8	2.1	0.46	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
CANTON—Concluded						
66	Stark-Tuscarawas Brewing Co., 624 Cherry St. Well, 80 ft., 5-in. casing in gravel. Pumps 200 gal. per minute for 24 hrs. Used in brewing and in boilers. See No. 67.	Pts. per mill.	438	327	227	100
		Grs. per gal.	25.5	19.1	13.2	5.8
67	Same location as 66. Well, 180 ft., 6-in. casing to rock at 90 ft., through rock to a soft white sandstone into which the drill penetrated 4 ft. Pumps 200 gal. per minute. Feed water of boilers made up of four-fifths from this well and one-fifth from well No. 66. Open heater is employed. No scale or sludge in boilers, but a little in the pipe lines. Heater cleaned every two weeks.	Pts. per mill.	302	132	227	None
		Grs. per gal.	17.6	7.7	13.2	
68	Troy Laundry & Dry Cleaning Co., 10th St., N. W. Drilled well, 324 ft., 10-in. casing to rock at 190 ft. Last 74 ft. was in sandstone ending in conglomerate rock. Pumps 50,000 gal. per day. Water is softened with lime only. No trouble in boilers.	Pts. per mill.	344	235	280	None
		Grs. per gal.	20.0	13.7	16.3	
69	Courtland Hotel, Tuscarawas St., N. W. Drilled well, 356 ft., 6-in. casing to rock at 200 ft. Pumps 40,000 gal. per day. Used in boilers. No scale trouble. Boilers washed out every three weeks.	Pts. per mill.	338	160	287	None
		Grs. per gal.	19.7	9.3	16.7	
70	Nimishillen Creek. Sample taken above city and above any factories.	Pts. per mill.	296	217	175	42
		Grs. per gal.	17.3	12.7	10.2	2.5
71	Nimishillen Creek. Sample taken below the steel mills in N. E. part of city.	Pts. per mill.	384	217	137	80
		Grs. per gal.	22.4	12.7	8.0	4.7
72	Nimishillen Creek. Sample taken after water has passed through city.	Pts. per mill.	748	410	137	273
		Grs. per gal.	43.6	23.9	8.0	15.9
73	Austin Lynch farm. On road between Canton and Massillon. Drilled well, 407 ft. Two other wells, 125 ft., on this farm, are reported as gradually decreasing in capacity.	Pts. per mill.	256	228	227	1
		Grs. per gal.	14.9	13.3	13.2	0.06

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
20	99	10	0.4	277	14	8.0	86	16	9	66
1.2	5.8	0.58	0.02	16.1	0.82	0.46	5.0	0.93	0.52	
13.4	31	60	1.4	277	14	2.0	12	26	7	67
0.78	1.8	3.5	0.08	16.1	0.82	0.12	0.70	1.5	0.40	
17	66	41	2.2	342	16	0.25	15	30	14	68
0.99	3.9	2.4	0.13	19.9	0.93	0.01	0.87	1.75	0.82	
17	36	71	0.8	350	24	2.5	Very little	22	15	69
0.99	2.1	4.1	0.04	20.4	1.4	0.15		1.3	0.87	
14.6	63	8.4	1.2	213	8	8.5	41	10	16	70
0.85	3.7	0.49	0.07	12.4	0.46	0.50	2.4	0.58	0.93	
17	59	28	4.8	167	24	6.0	76	28	31	71
0.99	3.4	1.6	0.28	9.8	1.4	0.35	4.4	1.6	1.8	
34	108	44	20	167	....	None	....	48	....	72
2.0	6.3	2.6	1.2	9.8	....		....	2.8	....
18	61	3	0.9	277	6	None	14	24	4	73
1.1	3.6	0.18	0.05	16.1	0.4		0.82	1.4	0.23	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
CASTALIA						
Sample taken in July, 1915.						
74	Blue Hole Spring. This famous spring is about a quarter of a mile from the village of Castalia and about 3 miles from the upper end of Sandusky Bay. A prodigious flow of water wells up from a fissure about 80 by 100 ft. in the limestone rock.	Pts. per mill.	1664	1107	202	905
		Grs. per gal.	97.0	64.6	11.8	52.8
CHARDON						
Samples taken in January, 1916.						
NOTE. Very little information concerning these wells was obtainable. They range from 35 to 70 ft. in depth.						
75	W. G. Sampson.....	{ Pts. per mill. Grs. per gal.	328 19.1	234 13.6	150 8.8	84 4.9
76	C. N. Quirk.....	{ Pts. per mill. Grs. per gal.	398 23.2	238 13.9	12 0.70	226 13.2
77	T. C. Compton.....	{ Pts. per mill. Grs. per gal.	192 11.2	174 10.1	165 9.6	9 0.53
78	E. A. Cook.....	{ Pts. per mill. Grs. per gal.	218 12.7	151 8.8	80 4.7	71 4.1
79	Jacob Smith.....	{ Pts. per mill. Grs. per gal.	492 28.7	267 15.6	105 6.1	162 9.4
80	Mrs. Mary Parker.....	{ Pts. per mill. Grs. per gal.	526 30.7	395 23.0	265 15.5	130 7.6
81	R. R. Coughlin.....	{ Pts. per mill. Grs. per gal.	540 31.5	285 16.6	207 12.1	78 4.6
82	Orin Parks.....	{ Pts. per mill. Grs. per gal.	248 14.5	175 10.2	100 5.8	75 4.4
83	E. M. Latimer.....	{ Pts. per mill. Grs. per gal.	400 23.3	292 17.0	180 10.5	112 6.5
84	Town pump.....	{ Pts. per mill. Grs. per gal.	206 12.0	149 8.7	77 4.5	72 4.2

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
32	391	12	0.4	246	14	None	636	50	3	74
1.9	22.9	0.70	0.02	14.4	0.82		37.1	2.9	0.18	
17	66	12	0.1	183	26	35	28	....	30	75
0.99	3.9	0.70	0.01	10.7	1.5	2.0	1.6	....	1.8	
20	63	2.9	0.1	15	12	40	155	....	43	76
1.2	3.7	0.17	0.01	0.85	0.70	2.3	9.0	....	2.5	
15	46	5.5	0.04	201	4	0.5	10	....	23	77
0.88	2.7	0.32	0.002	11.7	0.23	0.03	0.58	....	1.3	
11	42	6	0.1	98	14	20	38	....	30	78
0.64	2.5	0.35	0.01	5.7	0.82	1.2	2.2	....	1.8	
21	73	23	1.0	128	48	74	45	....	35	79
1.2	4.3	1.3	0.06	7.4	2.8	4.3	2.6	....	2.0	
28	112	19	0.1	323	68	0.8	57	....	38	80
1.6	6.5	1.1	0.01	18.9	4.0	0.05	3.3	....	2.2	
21	80	63	3.8	252	16	55	56	....	33	81
1.2	4.7	3.7	0.22	14.8	0.93	3.2	3.3	....	1.9	
13.4	48	6	1.8	122	10	35	31	....	18	82
0.78	2.8	0.35	0.11	7.1	0.58	2.0	1.8	....	1.1	
22	81	6	0.06	220	32	25	44	....	33	83
1.3	4.7	0.35	0.004	12.8	1.9	1.5	2.6	....	1.9	
18	30	8	0.1	94	12	8	56	....	74	84
1.1	1.8	0.47	0.01	5.5	0.70	0.47	3.3	....	4.3	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
CHARDON—Concluded						
85	Dr. Swan.....	{ Pts. per mill. Grs. per gal.	422 24.6	268 15.6	140 8.2	128 7.5
86	W. Radcliff.....	{ Pts. per mill. Grs. per gal.	474 27.6	290 16.9	230 13.4	60 3.5
87	"Magnetic" well, west of Chardon.....	{ Pts. per mill. Grs. per gal.	266 15.5	245 14.3	207 12.1	38 2.2
88	Electric Light Plant.....	{ Pts. per mill. Grs. per gal.	358 20.9	309 18.0	220 12.8	89 5.2
89	Macaroni Factory.....	{ Pts. per mill. Grs. per gal.	288 16.8	107 6.2	227 13.2	None
90	Wesley Goodrich.....	{ Pts. per mill. Grs. per gal.	1774 103.0	318 18.5	52 3.0	266 15.5
CHILLICOTHE						
Samples taken January 27, 1916.						
91	City Water Works. Two wells in sand and gravel, average depth 33 ft., walled with brick, pump 1,000,000 gal. per day. Used in boilers makes some scale. With Hawkeye boiler compound scale is kept loose.	{ Pts. per mill. Grs. per gal.	470 27.4	398 23.2	305 17.8	93 5.4
92	Meade Pulp & Paper Co. Eleven driven wells, average depth 45 ft., 8-in. casings. Pumpage estimated at 2,000,000 gal. per 24 hrs. In dry seasons the wells run low in supply. Softened with lime and soda ash for boiler use. Water is also used for paper making. Wire belt lasts only about four weeks in raw water. Cannot use it to make sizing because calcium precipitates rosin.	{ Pts. per mill. Grs. per gal.	624 36.4	482 28.1	347 20.2	135 7.9
93	Chillicothe Bottling Co. Drilled well, 87 ft. in sand and gravel, 10-in. casing. Pumps 200 gal. per minute. Used in boilers with graphite and soda ash forms very little scale. Open heater also employed.	{ Pts. per mill. Grs. per gal.	466 27.2	396 23.1	312 18.2	84 4.9

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
17	79	22	2.4	171	50	30	51	....	72	85
0.99	4.6	1.3	0.14	10.0	2.9	1.8	3.0	....	4.2	
15	92	52	0.14	281	44	55	62	....	40	86
0.88	5.4	3.0	0.01	16.3	2.6	3.2	3.6	....	2.3	
21	64	6	0.06	252	8	5	27	....	36	87
1.2	3.7	0.35	0.004	14.8	0.47	0.29	1.6	....	2.1	
23	85	5	0.3	268	20	1.5	58	....	29	88
1.3	5.0	0.29	0.02	15.6	1.2	0.09	3.4	....	1.7	
11	25	72	0.2	277	6	2.5	22	....	20	89
0.64	1.5	4.2	0.01	16.1	0.35	0.15	1.3	....	1.2	
22	91	473	0.3	63	800	50	59	....	50	90
1.3	5.3	27.6	0.02	3.7	46.7	2.9	3.4	....	2.9	
32	107	12	2.0	372	12	1.5	85	....	55	91
1.9	6.2	0.7	0.11	21.7	0.70	0.09	5.0	....	3.2	
41	125	28	0.1	423	34	8.5	111	....	59	92
2.4	7.3	1.6	0.01	24.6	2.0	0.49	6.5	....	3.4	
32	106	14	0.7	381	16	6	70	....	53	93
1.9	6.2	0.82	0.04	22.2	0.93	0.35	4.1	....	3.1	

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃	
CHILLICOTHE—Concluded						
94	Chillicothe Street Ry., Power & Light Co. Drilled well, 110 ft. in gravel, last 10 ft. being in blue clay. If well is pumped 48 hrs. it runs dry. Water used in boilers with open heater and Dearborn compound gives loose scale. If "lake" water which is used in part is muddy there is trouble from foaming.	Pts. per mill. Grs. per gal.	418 24.3	368 21.5	322 18.8	46 2.7
CINCINNATI						
Samples collected May 11 to 15, 1915						
95	City water. Water from the Ohio River is taken at a point about eight miles above the city. It is purified by first settling in large sedimentation basins and subsequently filtering through rapid sand filters after treatment with ferrous sulfate (copperas) and lime. Sample was taken from one of the city taps.	Pts. per mill. Grs. per gal.	174 10.1	85 5	27 1.6	58 3.4
96	St. Bernard Water Works, Oak St., St. Bernard. Two wells, 160 and 180 feet, 8-in. casings. Used in boilers after softening with lime and soda ash. Open heater employed contains heavy precipitate. Foaming trouble reported.	Pts. per mill. Grs. per gal.	560 32.7	430 25.1	377 22.0	53 3.1
97	Globe Soap Co., Carthage Pike and Big Four R. R. Two drilled wells, 280 ft., 10-in. casings. Water level 20 ft. from surface. This level reported falling. Pumps 900 gal. per minute for 10 hrs. For boiler use water is heated to boiling and treated with lime and soda ash. No hard scale.	Pts. per mill. Grs. per gal.	610 35.6	417 24.3	350 20.4	67 3.9
98	Harkness & Cowing Co., Carthage Pike & Murray Road. Driven well, 6-in. casing, in gravel. Pumps 20,000 gal. per day. Softened by We-fu-go system, water gives no trouble in boilers.	Pts. per mill. Grs. per gal.	442 25.8	352 20.5	310 18.1	42 2.5

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
29	99	10	7.4	393	8	None	44	....	41	94
1.7	5.8	0.58	0.43	22.9	0.47		2.6	....	2.4	
6.1	24	13	0.3	33	14	1.3	51	10	....	95
0.4	1.4	0.8	0.02	1.9	0.82	0.08	3.0	0.58	....
34	116.0	25	0.2	460	36	6.5	56	18	7	96
2.0	6.8	1.5	0.01	26.8	2.1	0.38	3.3	1.1	0.41	
32	115	35	0.5	427	64	0.25	58	24	7	97
1.9	6.7	2.0	0.03	24.9	3.7	0.01	3.4	1.4	0.41	
26	99	5.5	0.8	378	14	None	50	22	21	98
1.5	5.8	0.32	0.05	22.1	0.82		2.9	1.3	1.2	

TABLE XX

No.	Description		Total solids.	Total hardness, CaCO ₃ .	Carbonate or temporary hardness, CaCO ₃ .	Non-carbonate or permanent hardness, CaCO ₃ .
CINCINNATI—Continued						
99	Laidlaw-Dunn-Gordon Co., Elmwood Place. Two drilled wells, 100 ft., 8-in. casings. Water softened by "Industrial Water Softener" with lime and soda ash. Graphite also used in boilers. Some soft scale reported.	Pts. per mill.	412	345	312	33
		Grs. per gal.	24.0	20.1	18.2	1.9
100	Phillip Carey Manufacturing Co., Lockland. Two wells, 188 ft. in gravel, 12-in. casings. Water level 68 ft. from surface. Pump 1,800 gal. per minute. Mixed with canal water used in boilers after softening with lime and soda ash. Some hard scale reported.	Pts. per mill.	438	362	325	37
		Grs. per gal.	25.5	21.1	19.0	2.2
101	Stearns & Foster Co., Lockland. Three drilled wells, 280 ft., 180 ft. to rock, clay, then 100 ft. of sand, 6-, 8-, and 10-in. casings. This water reported as changing, increase in iron being especially noted. Used in boilers after softening by We-fu-go system	Pts. per mill.	516	390	337	53
		Grs. per gal.	30.1	22.8	19.7	3.1
102	Union Distilling Co., Carthage. Three drilled wells, 2-, 8-, and 10-in. casings. The 10-in. well is 170 ft. deep, in gravel. Used for condensing and then to soften. Before softening water gave much scale.	Pts. per mill.	422	360	322	38
		Grs. per gal.	24.6	21.0	18.8	2.2
103	Same location as 102. Well 135 ft., 8-in. casing.	Pts. per mill.	382	315	315	None
		Grs. per gal.	22.3	18.4	18.4	
104	M. B. Farrin Lumber Co., Station Ave., Winton Place. Drilled well, 133 ft., 10-in. casing. This well has been drilled to 250 ft. at which depth salt water was struck. It was then filled to 133 ft. Used for drinking.	Pts. per mill.	612	400	412	None
		Grs. per gal.	35.7	23.3	24.0	
105	Ohio Butterine Co., 50 Walnut St. Drilled well, 275 ft., 8-in. casing, into rock. Pumps 53 gal. per minute. Used for drinking and in boilers with compound. Some scale trouble.	Pts. per mill.	1046	565	405	160
		Grs. per gal.	61.0	33.0	23.6	9.3

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
26	96	4.2	0.5	381	14	None	37	16	4	99
1.5	5.6	0.25	0.03	22.2	0.82		2.2	0.93	0.23	
29	97	9.0	2.8	396	14	None	48	18	2.0	100
1.7	5.7	0.53	0.16	23.2	0.82		2.8	1.1	0.12	
33	102	13	6.6	411	36	0.75	46	20	4.0	101
1.9	5.9	0.76	0.39	24.0	2.1	0.04	2.7	1.2	0.23	
32	92	14	4.2	393	14	None	49	6.0	6.0	102
1.9	5.4	0.82	0.25	22.9	0.82		2.9	0.35	0.35	
28	80	4.5	2.9	384	14	1.5	Very	66	0.5	103
1.6	4.7	0.26	0.17	22.4	0.82	0.09	little	3.9	0.03	
38	98	77	6.2	503	112	None	None	14	6.0	104
2.2	5.7	4.5	0.36	29.3	6.5			0.82	0.35	
38	164	146	2.6	494	204	2.3	153	20	114	105
2.2	9.5	8.5	0.15	28.8	11.9	0.13	8.9	1.2	6.6	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
CINCINNATI—Continued						
106	National Candy Co., 25 Court St. Drilled well, 140 ft., in sand and gravel. Used for cooling.	Pts. per mill.	1966	1017	515	502
		Grs. per gal.	115.0	59.0	30.1	29.3
107	Foss-Schneider Brewing Co., Court and Freeman Ave. Four driven wells, 86 feet, 6-in. casings. Used for cooling.	Pts. per mill.	1320	530	534	None
		Grs. per gal.	77.0	30.9	31.1	
108	Jung Brewing Co., 2014 Freeman Ave. Three drilled wells, 156 feet, to rock, 8-in. casings. Total pumpage 300 gal. per min. Used for cooling and washing. Clogged up condensers.	Pts. per mill.	1928	922	577	345
		Grs. per gal.	113.0	53.8	33.7	20.1
109	John Huffman Packing Co., Baymiller near Central St. Driven well, 155 ft., 6-in. casing. Used for cooling.	Pts. per mill.	1718	940	572	368
		Grs. per gal.	100.0	54.8	33.4	21.5
110	Lackman Brewing Co., Carlisle and Stone St. Four drilled wells, 85 feet, 6-in. casing, in gravel. Pump 60 gal. per min. Used in ammonia condensers.	Pts. per mill.	1000	572	375	197
		Grs. per gal.	58.3	33.4	21.9	11.5
111	Crystal Spring Station City Ice Delivery Co., Apple St. Driven well, 115 ft., 6-in. casing, in sand and gravel. Used for cooling. It is reported of this water that if air strikes it before it enters the condensers the pipes fill up with scale, but if a closed system preventing the entrance of air is used there is no trouble, the pipes remaining perfectly clean.	Pts. per mill.	880	445	422	23
		Grs. per gal.	51.3	26.0	24.6	1.3
112	Jacob Schlachter & Sons Co., 2841 Colerain Ave. Drilled well, 90 ft., 6-in. casing, in gravel. Used for cooling and drinking.	Pts. per mill.	398	345	352	None
		Grs. per gal.	23.2	20.1	20.5	
113	Standard Carbonic Co., Burns St. Two wells, 101 ft., 8-in. casings, ending in gravel and rock. Pump 50 gal. per min. Used for cooling and drinking.	Pts. per mill.	930	627	445	182
		Grs. per gal.	54.3	36.6	26.0	10.6

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
80	250	150	13.2	628	450	None	190	14	66	106
5.3	15.1	9.1	0.77	36.7	26.3		11.1	0.82	3.9	
87	118	253	2.4	651	180	9.0	240	18	112	107
3.3	9.2	14.8	0.14	37.9	10.5	0.53	14.0	1.1	6.5	
75	245	280	19.2	704	480	None	240	8.0	108	108
4.4	14.3	16.7	1.1	41.1	28.0		14.5	0.47	6.3	
69	202	185	15.2	698	400	None	195	36	93	109
4.0	15.3	10.8	0.86	40.7	23.3		11.4	2.1	5.4	
43	159	70	0.7	457	94	40	126	26	64	110
2.5	9.3	4.1	0.04	26.7	5.5	2.3	7.4	1.5	3.7	
40	112	151	7.2	515	236	None	Very little	10	8.0	111
2.3	6.5	8.8	0.42	30.0	13.8			0.58	0.47	
29	90	16	5.4	429	16	None	Very little	48	16	112
1.7	5.3	0.93	0.32	25.0	0.93			2.8	0.93	
44	179	37	4.0	543	56	None	155	62	58	113
2.6	10.4	2.2	0.23	31.7	3.3		9.1	3.6	3.4	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or tem- porary hardness, CaCO ₃	Non- carbonate or per- manent hardness, CaCO ₃
CINCINNATI—Concluded						
114	Butchers Packing Co., 539 Poplar Ave. Two wells, 155 ft., ending in gravel. Six feet of stone struck before drill en- tered water-bearing gravel. Used for cooling and condensing.	Pts. per mill.	3042	1205	735	470
		Grs. per gal.	177.0	70.3	42.9	27.4
115	John H. McGowan & Co., 54 Central Ave. Drilled well, 70 ft., 5-in. casing, in gravel. Pumps 20 gal. per min.	Pts. per mill.	1008	442	305	137
		Grs. per gal.	59.0	25.8	17.8	8.0
116	Liquid Carbonic Co., 2nd and Central Ave. Drilled well, 80 ft., 8-in. casing, in gravel. Pumps 30 gal. per min. Used for cooling.	Pts. per mill.	1150	457	292	165
		Grs. per gal.	67.0	26.7	17.0	9.6
CIRCLEVILLE						
Samples collected January 15, 1916.						
117	City water. Water is taken from Dark Creek and filtered. Sample was from a consumer's tap.	Pts. per mill.	428	376	315	61
		Grs. per gal.	25.0	21.9	18.4	3.6
118	C. E. Sears & Co., South Washington St. Drilled well, 96 ft., 8-in. casing. Goes into gravel 12 to 15 ft. Used in boilers with compound. Some scale.	Pts. per mill.	390	347	282	65
		Grs. per gal.	22.8	20.2	16.4	3.8
119	Heffner Mill Co., East Mill St. Drilled well, 78 ft., 6-in. casing through gravel and sand. Used in boilers with com- pound.	Pts. per mill.	520	415	275	140
		Grs. per gal.	30.3	24.2	16.0	8.2
120	Circleville Grain Co., West Main St. Driven well, 61 ft. Used in boilers with compound. No trouble reported.	Pts. per mill.	574	455	290	165
		Grs. per gal.	33.5	26.6	16.9	9.6
121	Circleville Light & Power Co. Driven well, 85 ft. Used in boilers with feed water heater.	Pts. per mill.	612	489	330	159
		Grs. per gal.	35.7	28.5	19.3	9.3
122	Hasler Packing Co., South Court St. Driven well, 135 ft., 6-in. casing, ends in sand and gravel. Used in boilers with compound. Small amount of scale re- ported.	Pts. per mill.	542	441	362	79
		Grs. per gal.	31.6	25.7	21.1	4.6

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
167	3.0	454	12.8	897	720	None	306	64	140	114
6.2	17.0	26.5	0.75	52.3	42.0		17.9	3.7	8.2	
32	125	125	0.2	372	168	19	106	42	56	115
1.0	7.3	7.3	0.01	21.7	9.8	1.1	6.2	2.5	2.1	
32	131	165	0.2	350	220	23	104	24	31	116
1.8	7.0	9.6	0.01	20.7	12.8	1.3	6.1	1.4	1.8	
32	8	8.0	0.3	384	8.0	6.0	60	....	55	117
1.0	3.7	0.47	0.02	22.4	0.47	0.35	3.5	....	3.2	
30	8	8.0	1.3	344	8.0	None	65	....	42	118
1.8	3.2	0.47	0.08	20.0	0.47		3.8	....	2.5	
33	112	12.0	0.2	335	8.0	7.0	118	....	40	119
1.9	6.5	0.70	0.01	19.5	0.47	0.41	6.9	....	2.3	
37	120	10.0	3.4	354	14.0	None	141	....	55	120
2.2	7.0	0.58	0.20	20.6	0.82		8.2	....	3.2	
42	126	18.0	3.8	403	26.0	None	135	....	52	121
2.5	7.4	1.1	0.22	23.5	1.5		7.9	....	3.0	
37	114	27	2.0	442	26.0	None	81	....	45	122
2.2	6.6	1.6	0.12	25.7	1.5		4.7	....	2.6	

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
CLEVELAND					
Samples collected Sept. 26-30, 1915.					
123	City water. Kirtland St. Water from Lake Erie, intake being 5 miles from shore. Treated with chloride of lime to make safe for drinking. Average hardness 92 parts per million. Does not vary more than 2 or 3 parts. When used in boilers with soda gives comparatively soft scale. The Cleveland Provision Co., also uses city water in its boilers along with tobacco extract and sodium phosphate. This keeps the scale loose.				
	Pts. per mill.	156	112	100	12
	Grs. per gal.	9.1	6.5	5.8	0.70
124	Same location as No. 123. Raw lake water. Used successfully in boilers with Dearborn compound. (See No. 129.)				
	Pts. per mill.	156	100	97	3.0
	Grs. per gal.	9.1	5.8	5.7	0.18
125	Cleveland Provision Co., Canal Road. Two wells 185 feet, 8-in. casings, end in gravel and blue clay. Pump 500 gal. per min. Used for washing and cooking. City water is used in boilers. (See No. 123.)				
	Pts. per mill.	422	92	267	None
	Grs. per gal.	24.6	5.4	15.6	
126	Standard Oil Co. Works No. 1, 2811 Broadway. Cuyahoga River water, untreated. Used in boilers with compound "caustic" and graphite. This keeps scale loose. Intends, however, to install a softening system.				
	Pts. per mill.	692	258	132	126
	Grs. per gal.	40.4	15.0	7.6	7.4
127	Cleveland Paper Co., Broadway. Drilled well, 125 feet. Used for drinking.				
	Pts. per mill.	328	55	212	None
	Grs. per gal.	19.1	3.2	12.4	
128	Cleveland Furnace Co., Clark Ave. Sixty driven wells, 25 to 31 feet deep, 4-in. casing, ending in sand. Used for cooling				
	Pts. per mill.	1138	570	115	455
	Grs. per gal.	66.3	33.3	6.7	26.6

GROUND WATERS OF OHIO Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
9.7	29	8.0	0.2	122	8.0	None	10	10	None	123
0.57	1.7	0.47	0.01	7.1	0.47		0.58	0.58		
8.5	26	13	0.3	118	8.0	None	12	6.0	None	124
0.50	1.5	0.76	0.02	7.0	0.47		0.70	0.35		
13.4	15	124	1.1	326	74	None	None	18	9.0	125
0.77	0.88	7.3	0.06	19.0	4.3			1.1	0.53	
22	67	104	12.0	161	162	None	122	14	19	126
1.3	3.9	6.0	0.70	9.3	9.4		7.1	0.81	1.1	
7.3	10	99	0.4	259	46	None	None	16	4.0	127
0.43	0.58	5.8	0.02	15.1	2.7			0.93	0.23	
44	156	52	41.6	140	90	None	390	22	94	128
2.6	9.1	3.0	2.4	8.2	5.3		22.8	1.3	5.5	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
CLEVELAND—Concluded						
129	New York Central Shops, 541 152nd St. Lake water taken 1,200 feet from shore. Used in stationary and locomotive boilers with soda ash. Not much trouble from scale.	Pts. per mill.	170	120	97	23
		Grs. per gal.	9.9	7.0	5.7	1.3
130	American Wire & Steel Co., Cuyahoga Works. Ohio Canal water, untreated. Sample taken was slightly turbid though as a rule water is clear. Softened by We-fu-go system, treated with ferrous sulfate as coagulant and then filtered through sand. Used in boilers. Trisodium phosphate added also, in boilers. Some hard scale reported.	Pts. per mill.	682	210	142	68
		Grs. per gal.	39.8	12.3	8.3	4.0
131	Same location as No. 130. Filtered canal water.	Pts. per mill.	684	196	145	51
		Grs. per gal.	39.9	11.4	8.5	3.0
132	Grasselli Chemical Co., Independence Road. Drilled well, originally put down for gas, now plugged at 350 feet, 8-in. casing. It is intended to use water for cooling.	Pts. per mill.	552	80	210	None
		Grs. per gal.	32.2	4.7	12.3	
133	American Steel & Wire Co., Central furnaces. Raw Cuyahoga River water.	Pts. per mill.	642	250	127	123
		Grs. per gal.	37.4	14.6	7.4	7.2
134	Same location as No. 133. River water after softening with lime, soda ash, and ferrous sulfate. No boiler trouble reported. Total cost of softening is given as 4.5 cents per 1,000 gal.	Pts. per mill.	462	63	(⁸)	63
		Grs. per gal.	26.9	3.7		3.7

⁸Normal carbonate = 40 pts. per mill. or 2.3 grs. per gal.
Hydroxide = 10 pts. per mill. or 0.58 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
11	50	6.2	0.7	118	12	0.6	13	12	2.0	129
0.64	1.8	0.36	0.04	7.0	0.70	0.04	0.76	0.70	0.12	
16	58	136	1.0	173	204	5.5	76	18	5.0	130
0.93	3.4	7.9	0.06	10.1	11.9	0.32	4.4	1.1	0.29	
16	52	149	0.8	177	204	6.5	75	10	5.0	131
0.93	3.0	8.7	0.05	10.4	11.9	0.38	4.4	0.58	0.29	
8.5	18	175	1.8	256	166	None	...	44	3.0	132
0.50	1.1	16.2	0.11	15.0	9.7		...	2.6	0.18	
20	68	100	16	155	136	9.5	133	40	32	133
1.2	4.0	5.8	0.93	9.0	7.9	0.55	7.8	2.3	1.9	
2.4	21	130	0.1	...	120	None	133	22	None	134
0.14	1.2	7.6	0.01	...	7.0		7.8	1.3		

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃	
COLUMBUS						
Samples collected Dec., 1914, and Jan., 1915.						
135	City water. The Columbus supply is obtained from a reservoir formed by damming the Scioto River above the city. This reservoir holds 7,000,000,000 gal. The water flows down the bed of the stream to the intake of the water works where it is softened with lime and soda ash, a coagulant is then added and it is filtered through rapid sand filters. At times chloride of lime is also employed to insure complete destruction of bacteria. Twelve power plants were found using this water in their boilers. Four of them gave no report; four reported "no trouble;" four reported some scale, and one of this last group, a railroad company, using the water in locomotive boilers, had some pitting.	Pts. per mill.	....	88	60	28
		Grs. per gal.	....	5.1	3.5	1.6
136	Buckeye Steel Castings Co., South Parsons Ave. Drilled well, 62 feet. Used in boilers with soda ash.	Pts. per mill.	656	480	312	168
		Grs. per gal.	38.3	28.0	18.1	9.8
137	Same location as No. 136 well.	Pts. per mill.	630	468	320	148
		Grs. per gal.	36.8	27.3	18.7	8.6
138	Columbus Iron & Steel Co., S. Parsons Ave. Driven well. Used in boilers after treatment with lime and soda ash. Capacity of three drift wells of this company is 150,000 gal. per 24 hours.	Pts. per mill.	786	530	366	164
		Grs. per gal.	45.9	30.9	21.4	9.6
139	Same location as No. 138. Driven well.	Pts. per mill.	762	466	360	106
		Grs. per gal.	44.4	27.2	21.0	6.2
140	Hoster-Columbus Co., Livingston Ave. & Front St. Drilled well, 120 feet, 6-in. casing. Used in ammonia condensers and then in boilers.	Pts. per mill.	956	632	396	236
		Grs. per gal.	56	36.9	23.1	13.8
141	Same location as No. 140. North well in malt room.	Pts. per mill.	938	647	410	237
		Grs. per gal.	54.7	37.7	23.9	13.8

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium Potas- sium), Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
12.06	.....	.....	.....	.....	.....	.....	.....	.....	.....	135
0.7	.....	.....	.....	.....	.....	.....	.....	.....	.....
39	128	.....	1.5	380.6	12	0.7	162	.....	.....	136
2.8	7.8	.....	0.05	22.1	0.70	0.04	9.4	.....	.....
36	128	.....	1.7	390	11	None	139	.....	.....	137
2.1	7.5	.....	0.10	22.8	0.64		8.1	.....	.....
46	137	.....	2.8	446	24	None	180	.....	.....	138
2.7	8.0	.....	0.16	26.1	1.4		10.5	.....	.....
37	126	.....	3.1	439	39	None	196	.....	.....	139
2.2	7.4	.....	0.18	25.6	2.3		11.4	.....	.....
55	161	.....	7.4	483	76	None	212	.....	40.0	140
3.2	9.4	.....	0.43	28.2	4.4		12.4	.....	2.3	
54	169	.....	9.9	500	31	None	214	.....	34	141
3.2	9.8	.....	0.58	29.2	1.8		12.5	.....	2.0	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
COLUMBUS—Continued						
142	Same location as No. 140. Well in brew house, 126 feet. Used for washing.	Pts. per mill.	1061	692	380	312
		Grs. per gal.	62.0	40.4	22.2	18.2
143	Same location as No. 140. Well, 90 feet. Used for washing.	Pts. per mill.	1008	687	420	267
		Grs. per gal.	59.0	40.0	24.5	15.6
144	Same location as No. 140. Well in pump room. Used in ammonia condensers and then in boilers.	Pts. per mill.	980	667	422	245
		Grs. per gal.	57.0	38.9	24.6	14.3
145	Same location as No. 140. Two wells, 122 feet, 8- and 10-in. casings. Used in boilers after preheating with exhaust steam. Live steam purifier also employed. Water treated with soda ash. Boiler tubes painted with graphite every winter. No pitting, some scale.	Pts. per mill.	900	660	387	273
		Grs. per gal.	53.0	38.5	22.5	15.9
146	Schlee's Branch, Hoster - Columbus Brewing Co., Front and Hoster Sts. Drilled well east side pump room, 100 feet, ends in drift. Used in boilers with soda ash. No scale trouble.	Pts. per mill.	1082	755	400	355
		Grs. per gal.	63.0	44.0	23.3	20.7
147	Same location as No. 146. West well in pump room.	Pts. per mill.	1234	840	415	425
		Grs. per gal.	72.0	49.0	24.2	24.8
148	Same location as No. 146. Brew house well, 110 feet.	Pts. per mill.	766	575	405	170
		Grs. per gal.	44.7	33.5	23.6	9.9
149	Schmidt Packing Co., 253 Kossuth St. Drilled well, 76 feet, 6-in. casing, ends in gravel. Pumps 75,000 gal. per day. Used in boilers with graphite. Great deal of scale reported.	Pts. per mill.	570	477	397	80
		Grs. per gal.	33.3	27.8	23.1	4.7
150	Ohio Brewing Co., Reeb Ave. and High St. Drilled well, 40 feet, in drift. Used for washing.	Pts. per mill.	1380	905	317	588
		Grs. per gal.	80.0	52.8	18.4	34.3

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
59 3.4	179 10.4	...	5.9 0.34	46.4 27.1	53 3.1	None	260 15.2	...	28 1.6	142
60 3.5	176 10.3	...	5.2 0.30	512 29.9	58 3.4	None	228 13.3	...	43 2.5	143
59 3.4	169 9.8	...	8.5 0.50	515 30.0	49 2.9	None	220 12.8	...	42 2.5	144
61 3.6	164 9.5	...	2.4 0.14	472 27.5	14 0.51	None	255 14.8	...	18 1.1	145
66 3.9	194 11.3	...	4.8 0.28	488 28.4	30 1.8	None	297 17.3	...	36 2.1	146
79 4.6	206 12.0	...	8.8 0.51	506 29.5	38 2.2	None	394 22.9	...	37 2.2	147
50 2.9	148 8.7	...	4.2 0.25	494 28.8	24 1.4	None	214 12.4	...	34 2.0	148
46 2.7	115 6.7	...	2.2 0.13	484 28.2	8.0 0.46	None	105 6.1	...	18 1.1	149
83 4.8	226 13.3	39 2.3	0.7 0.04	387 22.4	50 2.9	18.5 1.1	330 19.2	44 2.6	39 2.3	150

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
COLUMBUS—Continued						
151	Same location as No. 150. Drilled well, 190 feet, last 100 feet in rock. Used in ammonia condensers. Was tried in boilers but given up on account of excessive scale. Water contains hydrogen sulfide.	Pts. per mill.	3480	1910	305	1605
		Grs. per gal.	203	111	17.8	94.0
152	Columbus Packing Co., South High St. Two wells, 43 feet, in gravel. Pump 300 gal. per minute. Used in boilers with preheating to about 204° F. Soda ash is also added to heater. Boilers are blown off twice a day.	Pts. per mill.	702	530	347	183
		Grs. per gal.	40.9	30.9	20.2	10.7
153	Same location as No. 152. Drilled well, 87 feet, ends in quicksand. Was used in boilers but gave too much hard scale.	Pts. per mill.	572	372	307	65
		Grs. per gal.	33.3	21.7	17.9	3.8
154	Southern Hotel, Main and High Sts. Drilled well, 127 feet, through rock and hard pan, ending in sand. It was reported that wood was struck at the bottom.	Pts. per mill.	902	600	377	223
		Grs. per gal.	53.0	35.0	22.0	13.0
155	Smith Agricultural Chemical Co., Hayes Ave. Drilled well, 270 feet, going through rock and ending in clay. Water was used in boilers but caused much corrosion and some scale. There is a belief around the plant that acid may have gotten into the water.	Pts. per mill.	780	290	352	None
		Grs. per gal.	45.5	16.9	20.5	
156	Franklin Brewing Co., 585 Cleveland Ave. Three drilled wells, 200 feet. Water was tried in boilers but caused too much scale; also some pitting, is now employed for condensing.	Pts. per mill.	2382	1480	240	1240
		Grs. per gal.	139	86.0	14.0	72.0
157	Same location as No. 156. Wash house well.	Pts. per mill.	830	605	420	185
		Grs. per gal.	48.4	35.3	24.5	10.8
158	Same location as No. 156. Ice house well.	Pts. per mill.	1322	972	420	552
		Grs. per gal.	77.0	57.0	24.5	32.2

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium & Potas- sium, Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
176	474	90	0.6	372	122	None	804	84	25	151
10.3	27.6	5.3	0.04	21.7	7.1		46.8	4.9	1.5	
34	159	.....	2.7	423	48	None	159	.....	34	152
2.0	8.1	.....	0.16	24.6	2.8		9.2	.....	2.0	
36	89	.....	18.4	374	26	None	70	.....	14	153
2.1	5.2	.....	1.1	21.8	1.5		4.1	.....	8.1	
52	154	.....	3.8	460	50	None	230	.....	24	154
3.0	8.0	.....	0.22	26.8	2.9		13.4	.....	1.4	
33	62	.....	0.8	429	8.0	2.6	220	.....	4.0	155
1.9	3.6	.....	0.05	25.0	0.46	0.15	12.8	.....	0.23	
125	386	.....	0.4	293	42	0.5	912	.....	6.0	156
7.3	22.5	.....	0.02	17.1	2.5	0.03	53.0	.....	0.35	
59	144	.....	2.3	512	20.0	None	200	.....	14.0	157
3.4	8.3	.....	0.13	29.8	1.2		11.6	.....	0.81	
80	257	.....	0.3	512	48	None	460	.....	9.0	158
4.7	15.0	.....	0.02	29.9	2.8		26.8	.....	0.52	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
COLUMBUS—Continued						
159	Jeffrey Manufacturing Co., First Ave. and Fourth St. Drilled well, 200 feet, 8-in. casing. Was tried in boilers but gave too much scale.	Pts. per mill.	2848	1714	297	1417
		Grs. per gal.	166	100	17.3	83.0
160	Same location as No. 159. Well, 205 feet.	Pts. per mill.	2852	1734	280	1454
		Grs. per gal.	166	101	16.3	85.0
161	Kilbourne & Jacobs Co., Lincoln and Fourth Sts. Well, 3,200 feet, 8-in. casing. This was drilled originally for gas. Water level 80 feet from surface. Contains hydrogen sulfide.	Pts. per mill.	3222	1950	295	1655
		Grs. per gal.	188	114	17.2	97.0
162	Butchers & Grocers Ice Co., East Second Ave. and B. & O. R. R. Three drilled wells, 250 feet, struck rock at 150 feet. Used for cooling and condensing. Contains hydrogen sulfide. Tried in boilers but caused scale and pitting.	Pts. per mill.	1658	1004	152	852
		Grs. per gal.	97.0	59.0	8.9	49.7
163	Columbus Railway, Power & Light Co., Mound and Central Ave. Pond fed by surface and spring water. Used in boilers, feed water being preheated.	Pts. per mill.	712	475	172	303
		Grs. per gal.	41.5	27.7	10.0	17.7
164	Stephens & Son, Brown Road, Greenlawn Cemetery. Drilled well, 54 feet, rock struck 4 feet from surface. Used in boilers and greenhouse heating system. Graphite employed. Some soft scale forms.	Pts. per mill.	645	465	326	139
		Grs. per gal.	37.6	27.1	19.0	8.0
165	State Hospital for Feeble Minded, West Broad St. Boiler room well, 209 feet, rock struck at 21 feet. The four wells at this institution pump 350,000 gal. per day. Used in boilers with open heater. Not much scale trouble. Tubes cleaned every 6 to 8 weeks. No pitting.	Pts. per mill.	761	565	352	213
		Grs. per gal.	44.4	32.9	20.5	12.4
166	Same location as No. 165. Well No. 1, pump house, 206 feet.	Pts. per mill.	562	455	382	73
		Grs. per gal.	32.8	26.5	22.3	4.3

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
149	440	....	0.6	36.2	40	None	1024	....	7.0	159
8.7	25.6	....	0.03	21.1	2.3		60.0	....	0.41	
151	440	....	2.4	34.2	38	0.5	1112	....	8.0	160
8.8	26.0	....	0.14	19.9	2.2	0.03	65.0	....	0.46	
165	508	....	1.2	36.6	76	None	1455	....	10.0	161
9.6	28.7	....	0.07	21.0	4.4		85.0	....	0.58	
74	272	....	0.8	18.5	22	1.7	857	....	3.0	162
4.9	15.9	....	0.05	10.9	1.3	0.10	50.0	....	0.18	
32	138	....	0.2	21.0	20	33	272	....	5.0	163
1.9	8.6	....	0.01	12.2	1.2	1.9	15.9	....	0.29	
39	122	....	0.8	39.8	47	12	74	....	33	164
2.3	7.1	....	0.05	23.2	2.7	0.7	4.3	....	1.9	
50	144	....	3.8	429	12	None	253	....	27	165
2.9	8.4	....	0.22	25.0	0.70		14.8	....	1.6	
41	115	....	3.8	466	8.0	None	104	....	10.0	166
2.4	6.7	....	0.22	27.2	0.46		6.0	....	0.58	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
COLUMBUS—Continued						
167	Same location as No. 165. Well No. 2, pump house.	Pts. per mill. Grs. per gal.	533 31.1	425 24.8	370 21.6	55.0 3.2
168	Same location as No. 165. Well No. 3, pump house.	Pts. per mill. Grs. per gal.	540 31.5	427 24.9	376 21.9	51 3.0
169	State Hospital for Insane, West Broad St. Well No. 1, boiler house, 275 feet, 10-in. casing. Rock struck at 155 feet. Water from this well and also from Nos. 170, 172, and 173 is pumped into a common cistern for use in boilers. An open heater brings the feed water to about 190° F. Boilers are blown off every 8 hours. There is much hard scale. One man kept busy drilling tubes. Water from No. 171 is seldom mixed with rest. Combined pumpage 350,000 gal. daily. This capacity is reported constant.	Pts. per mill. Grs. per gal.	620 36.2	472 27.5	338 19.7	134 7.9
170	Same location as No. 169. Middle well, No. 2, 300 feet, 10-in. casing.	Pts. per mill. Grs. per gal.	810 47.3	565 32.9	312 18.1	253 14.7
171	Same location as No. 169. Well No. 3, 410 feet, 10-in. casing. Contains hydrogen sulfide. "Not used in boilers any more than can be helped."	Pts. per mill. Grs. per gal.	1332 78.0	850 49.6	298 17.4	552 32.2
172	Same location as No. 169. Well No. 4, 308 feet, 8-in. casing.	Pts. per mill. Grs. per gal.	540 31.5	455 26.6	372 21.7	83 4.8
173	Same location as No. 169. Well No. 5, side of engine house, 300 feet, 10-in. casing, 155 feet to rock. At 300 feet a stratum of soft grayish shale was struck. On test this well pumped 225 gal. per minute.	Pts. per mill. Grs. per gal.	570 33.3	430 25.1	342 19.9	88 5.1
174	Concrete Materials Co., Dublin Pike. Pond in gravel bed, 20 feet deep. Used in both stationary and locomotive boilers. Not much scale trouble. Quit using boiler compound. About $\frac{1}{16}$ in. hard scale forms in tubes in six months.	Pts. per mill. Grs. per gal.	508 29.7	375 21.9	190 11.1	185 10.8

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium Potassium, Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
57 2.2	109 6.3		1.4 0.08	451 26.4	6.0 0.35	None	73 4.3	.....	8.0 0.46	167
56 2.1	111 6.8		3.1 0.18	459 26.7	8.0 0.49	None	71 4.1	.....	8.0 0.46	168
44 2.7	117 6.8		0.6 0.04	412 24.0	9.0 0.53	None	149 8.7	.....	18 1.1	169
52 3.0	141 8.2		0.6 0.04	381 22.1	14 0.82	None	276 16.1	.....	10.0 0.58	170
76 4.4	215 12.5		6.0 0.04	363 21.2	83 4.8	None	468 27.3	.....	9.0 0.53	171
43 2.5	112 6.5		2.8 0.16	454 26.5	8.0 0.46	None	112 6.5	.....	15 0.88	172
39 2.3	108 6.3		0.8 0.05	417 24.3	6.0 0.35	None	124 7.2	.....	5.0 0.29	173
30 1.8	100 5.8	8.8 0.51	0.6 0.04	232 13.5	14 0.82	2.5 0.15	159 9.2	32 1.9	2.0 0.12	174

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
COLUMBUS—Continued						
175	T. E. Guy, Arlington and Fifth Ave. Drilled well, 58 feet, last 28 feet in sand and gravel. Used for watering and heating greenhouse.	Pts. per mill.	480	410	315	95
		Grs. per gal.	28.0	23.9	18.4	5.5
176	Joseph Schoenthal Iron Co., Buttles Ave. and Factory St. Driven well, 90 feet, in sand and gravel. Used for cooling gas engines.	Pts. per mill.	890	620	332	288
		Grs. per gal.	52.0	36.2	19.4	16.8
177	Capital City Dairy Co., First Ave. and Perry St. Four driven wells, 90 to 110 feet, ending at rock. Used for cooling and condensing. Contains hydrogen sulfide.	Pts. per mill.	1000	670	302	368
		Grs. per gal.	58.3	39.1	17.6	21.4
178	Same location as No. 177. Well, 100 feet, ending in rock.	Pts. per mill.	732	550	287	263
		Grs. per gal.	42.7	32.1	16.7	15.3
179	Same location as No. 177. Well, 100 feet.	Pts. per mill.	1476	917	322	595
		Grs. per gal.	86.0	53.5	18.8	34.7
180	Washington Brewery Co., Second Ave. and Perry St. Drilled well, No. 1, 109 feet ending in rock. Used for cooling and condensing. Does not pit condensers. Used for making beer but is first boiled. Was tried in boilers but gave too much scale.	Pts. per mill.	1204	850	337	513
		Grs. per gal.	70.2	49.6	19.7	29.9
181	Same location as No. 180. Well No. 2, 106 feet.	Pts. per mill.	1148	782	287	495
		Grs. per gal.	67.0	45.6	16.7	28.9
182	Excelsior Seat Co. On river road between King and Fifth Aves. Drilled wells, 51 feet, 6-in. casings. Used in boilers with graphite which prevents scale sticking to tubes. Feed water is heated in tank by running exhaust steam into it after which it passes to a Hoppes heater, then to boiler.	Pts. per mill.	546	427	267	160
		Grs. per gal.	31.8	24.9	15.6	9.3

GROUND WATERS OF OHIO—Continued

Calcium, Mg	Calcium, Ca	Sodium Potas- sium, Na	Iron, Fe	Bicar- bonate ion, HCO	Chloride ion, Cl	Nitrate ion, NO	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
36	104	5.2	0.4	384	6.0	15	75	28	27	175
2.1	6.0	0.30	0.02	22.4	0.35	0.88	4.4	1.6	1.6	
57	154		7.4	405	28	None	322	....	20	176
3.3	9.0	...	0.43	23.7	1.6		18.8	...	1.2	
61	168	27	1.0	368	50	0.25	331	26	6.0	177
3.6	9.8	1.6	0.06	21.5	2.9	0.01	19.3	1.5	0.35	
51	136	10.7	1.4	350	16	0.25	262	36	6.0	178
3.0	8.0	0.62	0.08	20.4	0.93	0.01	15.3	2.1	0.35	
84	229	84	1.0	393	136	None	492	34	7.0	179
4.9	13.3	4.9	0.06	22.9	7.9		28.7	2.0	0.41	
73	220	.	2.0	411	22	None	480	....	9.0	180
4.3	12.8	....	0.12	24.0	1.3		28.0	....	0.53	
72	195	....	1.0	350	19	None	464	....	13	181
4.2	11.4	....	0.06	20.4	1.1		27.0	....	0.76	
28	125	....	2.2	326	8.0	None	194	....	17	182
1.6	7.3	....	0.13	19.0	0.46		11.3	....	0.99	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
COLUMBUS—Continued						
183	Same location as No. 182. Drilled well, 32 feet. Used for drinking.	Pts. per mill.	520	380	258	122
		Grs. per gal.	30.3	22.2	15.0	7.1
184	Weisheimer Flour Co., King Ave. and Hocking Valley R. R. Drilled well, 90 feet, 6-in. casing, ending in rock. Used in boiler with soda ash. Feed water preheated with exhaust steam. Scale can all be blown off. There is a little trouble from foaming.	Pts. per mill.	450	397	267	130
		Grs. per gal.	26.3	23.2	15.6	7.6
185	Linden Heights School, Cleveland Ave. and Westerville road, Drilled well, 92 feet, 5-in. casing. Used for drinking.	Pts. per mill.	772	487	432	55
		Grs. per gal.	45.0	28.4	25.2	3.2
186	T. F. Johnson, 126 Arlington Ave., Linden Heights. Dug well, 20 feet, walled with brick.	Pts. per mill.	1590	420	205	215
		Grs. per gal.	93.0	24.5	12.0	12.5
187	Farmers Fertilizer Co., Windsor Ave. and C. A. & C. R. R. Well, 110 feet, 6-in. casing, ending in gravel. Used in condensers. Contains a trace of hydrogen sulfide.	Pts. per mill.	704	552	460	92
		Grs. per gal.	41.0	32.2	26.8	5.4
188	Same location as No. 187. Dug well, 30 feet, ending in gravel.	Pts. per mill.	938	560	317	243
		Grs. per gal.	54.7	32.7	18.4	14.2
189	National Ice & Storage Co., Fifth and Naghten Sts. Drilled well, 196 feet, 6-in. casing to rock at 80 feet. Used in condensers after running over cooling tower to get rid of hydrogen sulfide. Deposits large amount of sludge in condensers. There is also much pitting of the tubes and pipes.	Pts. per mill.	1548	1000	322	678
		Grs. per gal.	90.0	58.3	18.8	39.5
190	Mr. Palmer, Sunbury Pike near Alum Creek. Drilled well, 55 feet, in gravel. Flows constantly.	Pts. per mill.	664	462	302	160
		Grs. per gal.	38.7	26.9	17.6	9.3
191	E. Wightman, Lane Ave. and Hocking Valley R. R. Driven well.	Pts. per mill.	522	422	296	126
		Grs. per gal.	30.4	24.6	17.3	7.4

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
35 2.6	94 5.3	.....	5.0 0.29	315 18.3	8.0 0.46	None	114 6.6	..... .....	14 0.82	183
32 1.5	107 6.2	.....	2.4 0.14	326 19.0	8.0 0.46	None	95 5.5	..... .....	9.0 0.53	184
47 2.7	117 6.8	.....	7.6 0.44	527 30.7	8.0 0.46	0.35 0.02	68 4.0	..... .....	18 1.1	185
34 2.3	112 6.5	.....	0.6 0.04	250 14.6	40 2.3	19.4 1.1	153 8.9	..... .....	12 0.70	186
51 3.1	137 8.0	.....	2.9 0.17	561 32.7	6.0 0.35	0.35 0.02	129 7.5	..... .....	37 2.2	187
63 3.7	125 7.0	.....	2.1 0.12	387 22.4	20 1.2	2.6 0.15	276 16.1	..... .....	4.0 0.23	188
89 5.2	254 14.8	.....	3.3 0.19	393 22.9	42 2.5	0.35 0.02	560 32.7	..... .....	12 0.7	189
40 2.3	119 6.9	.....	2.0 0.12	368 21.5	8.0 0.47	None	184 10.7	..... .....	..... .....	190
34 2.0	113 6.6	.....	1.8 0.11	361 21.1	10 0.58	None	100 5.8	..... .....	16 0.93	191

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
COLUMBUS—Continued						
192	William Salzgeber, Lane Ave. west of Hocking Valley R. R. Drilled well, 120 feet.	Pts. per mill.	532	412	356	56
		Grs. per gal.	31.0	24.0	20.8	3.3
193	Fifth Ave. Floral Co., Sells Road. Well No. 1, drilled 87 feet, 6-in. casing, does not go into limestone. When used alone in boilers water is reported to give very little scale trouble.	Pts. per mill.	426	350	330	20
		Grs. per gal.	24.8	20.4	19.3	1.2
194	Same location as No. 193. Well No. 2, drilled, 108 feet, ending in limestone, 6-in. casing. Used in boilers with Pyramid compound to prevent scale from sticking.	Pts. per mill.	430	362	322	40
		Grs. per gal.	25.1	21.1	18.8	2.3
195	Livingston Seed Co., Sells Road. Well No. 1, 78 feet, 6-in. casing, ends in gravel. Used in boilers with Pyramid compound to prevent scale from sticking.	Pts. per mill.	486	392	290	102
		Grs. per gal.	28.4	22.9	16.9	5.9
196	Same location as No. 195. Well No. 2, 29 feet, in gravel. Used in boilers mixed with water from well No. 1. Pumpage from the two wells, 15,000 gal. daily.	Pts. per mill.	698	532	312	220
		Grs. per gal.	40.7	31.0	18.2	12.8
197	Same location as No. 195. Three dug wells, 30 feet.	Pts. per mill.	1024	647	300	347
		Grs. per gal.	60.0	37.7	17.5	20.2
198	Riverside Floral Co., corner of Sells and River roads. Driven well, 35 feet, ending in sand.	Pts. per mill.	638	470	297	173
		Grs. per gal.	37.2	27.4	17.3	10.0
199	Franklin County Children's Home, Sunbury Pike. Drilled well, 90 feet. Contains a little hydrogen sulfide.	Pts. per mill.	972	700	425	275
		Grs. per gal.	56.7	40.8	24.8	16.0
200	Ralston Steel Car Co., East Fifth Ave. Three drilled wells, 75 feet, ending in gravel, 8- and 6-in. casings. Used in boilers, mixed with rain water. Graphite boiler compound employed, also Cochran type feed water heater.	Pts. per mill.	492	405	397	8.0
		Grs. per gal.	28.7	23.6	23.2	.047

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
43	24	...	8.4	434	8.0	None	74	....	16	192
2.3	3.3	...	0.49	25.4	0.47		4.3	....	0.93	
36	70	...	11	403	8.0	None	37	....	19	193
2.3	4.4	...	0.64	23.5	0.47		2.2	....	1.1	
35	87	....	1.7	393	6.0	None	55	....	17	194
2.0	3.1	....	0.10	22.9	0.35		3.2	....	0.99	
35	60	....	1.8	354	16	None	84	....	13	195
2.0	3.8	...	0.11	20.6	0.93		4.9	....	0.76	
44	141	...	0.1	381	34	2.6	171	....	19	196
2.6	8.2	....	0.01	22.2	2.0	0.15	10.0	....	1.1	
58	163	....	4.0	366	58	17.6	264	....	7.0	197
3.4	9.5	....	0.23	21.4	3.4	1.0	15.4	....	0.41	
37	126	....	1.7	362	20	6.2	147	....	18	198
2.2	7.4	....	0.10	21.1	1.2	0.36	8.6	....	1.1	
66	172	....	4.6	518	10	None	267	....	21	199
3.9	10.0	....	0.27	30.3	0.58		15.6	....	1.2	
37	100	....	3.0	484	6.0	None	26	....	15	200
2.2	5.8	....	0.18	28.3	0.35		1.5	....	0.88	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
COLUMBUS—Continued						
201	Chittenden Hotel, High and Spring Sts. Drilled well, 114 feet, 10 feet into rock, 6-in. casing. Used for condensing.	Pts. per mill.	1578	945	412	533
		Grs. per gal.	92.0	55.1	24.0	31.1
202	Columbus Savings & Trust Building, Long and High Sts. Two drilled wells, about 50 feet, contain hydrogen sulfide.	Pts. per mill.	1574	955	447	508
		Grs. per gal.	92.0	55.7	26.1	29.6
203	Fairmont Creamery Co., Spring and Scioto Sts. Well No. 1, 89 feet, ending in rock. Water contains hydrogen sulfide. Used for condensing.	Pts. per mill.	514	320	175	145
		Grs. per gal.	30.0	18.7	10.2	8.5
204	Same location as No. 203. Well No. 2, 89 feet.	Pts. per mill.	464	310	170	140
		Grs. per gal.	27.1	18.0	9.9	8.2
205	Columbus Railway, Power & Light Co., East Gay St. Station. Drilled well, 90 feet. This was originally 50 feet in depth but went dry. It was then carried to 90 feet. Water at 90 feet was worse than that at 50 feet. Tried in boilers but caused too much scale and corrosion. Drums were pitted.	Pts. per mill.	1276	830	455	375
		Grs. per gal.	74.0	48.4	26.5	21.9
206	State House, High and Broad Sts. Driven well, 100 feet.	Pts. per mill.	1032	667	415	252
		Grs. per gal.	60.0	38.9	24.2	14.7
207	Furnas Ice Cream Co., 583 East Long St. Well No. 1, 70 feet, ending in gravel, 8-in. casing. Contains a little hydrogen sulfide. Used for ammonia condensers and for cooling gas engine. No serious trouble from scale. Pitted the pipes.	Pts. per mill.	790	577	370	207
		Grs. per gal.	46.1	33.7	21.6	12.1
208	Same location as No. 207. Well No. 2, 70 feet, ending in gravel. Same properties as No. 207.	Pts. per mill.	764	525	355	170
		Grs. per gal.	44.5	30.6	20.7	9.9
209	Gwinn Milling Co., East Main St. Drilled well, 39 feet, ending in gravel, 8-in. casing. Pumps 50,000 gal. daily. Used for condensing. Gave heavy scale when tried in boilers.	Pts. per mill.	616	462	295	167
		Grs. per gal.	35.9	26.9	17.2	9.7

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium Potas- sium, Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
89	232		2.6	503	164	None	297	....	36	201
5.2	13.5		0.15	29.3	9.5		17.3	....	2.1	
86	240		12.8	545	96	None	378	....	40	202
5.0	14.0		0.75	31.8	5.6		22.0	....	2.3	
29	8		2.4	213	8.0	8.8	95	....	5.0	203
1.7	4.7		0.14	12.4	0.47	0.51	5.5	....	0.29	
28	78		1.0	207	8.0	8.8	91	....	2.0	204
1.6	4.6		0.06	12.1	0.47	0.51	5.3	....	0.12	
73	212		12.4	535	50	None	291	....	48	205
4.5	12.4		0.72	32.3	2.9		17.0	....	2.8	
57	173	....	3.6	506	50	None	216	....	31	206
3.3	10.1	....	0.21	29.5	2.9		12.6	....	1.8	
51	147	....	3.5	451	62	None	180	....	27	207
3.0	8.6	....	0.20	26.4	3.6		10.5	....	1.6	
53	122	....	15.8	433	60	None	157	....	19	208
3.1	7.1	....	0.92	25.3	3.5		9.2	....	1.1	
57	123	....	1.8	360	8.0	None	162	....	12	209
2.2	7.2	....	0.11	21.0	0.47		9.4	....	0.70	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
COLUMBUS—Concluded						
210	H. Holtzman & Sons Co., 2094 East Main St. Drilled well, 80 feet, ending in gravel. Water level 15 feet from surface.	Pts. per mill.	692	530	367	163
		Grs. per gal.	40.4	30.9	21.4	9.5
211	G. B. Kauffman, North High St. above Olentangy Park, Stop 15. Drilled well, 173 feet, ending in limestone. Contains some hydrogen sulfide. Level of water 73 feet from surface.	Pts. per mill.	2012	1164	217	947
		Grs. per gal.	117	68.0	12.7	55.2
212	Ohio State University, spring on the campus.	Pts. per mill.	616	479	295	184
		Grs. per gal.	35.9	27.9	17.2	10.7
COSHOCTON						
Samples collected November 9, 1915.						
213	City water. Bridge St. Eleven drilled wells, 40 feet, 10-in. casings. One large well 28 feet in diameter, 35 feet deep, walled with stone. These wells are all in gravel and pump 2,000,000 gal. daily. The water varies with the stage of the river. Used in boilers in connection with a closed heater and some compound it is said to give but little scale trouble.	Pts. per mill.	492	282	177	105
		Grs. per gal.	28.6	16.4	10.3	6.1
214	Coshocton Light & Heating Co., North Fourth St. Drilled well, 77 feet, 6-in. casing. Pumps 75,000 gal. daily. Used in boilers after softening.	Pts. per mill.	752	438	235	203
		Grs. per gal.	43.9	25.5	13.7	11.8
215	Same location as No. 214. Water softened by We-fu-go system. No scale and no corrosion but foaming if water is over-treated. Average cost of softening, including all items, for a year, was 3½ cents per 1,000 gal.	Pts. per mill.	546	29	(10)	29
		Grs. per gal.	31.9	1.7	....	1.7

¹⁰Normal carbonate = 25 pts. per mill. or 1.5 grs. per gal.
Hydioxide = 55 pts. per mill. or 3.2 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium Mg	Calcium Ca	Sodium Potassium Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
4.5	1.8		0.14	448	31	4.8	144		22	210
2.6	8.5		0.01	26.1	1.8	0.28	8.4		1.3	
132	2.8	115	1.0	265	12	None	780	6.0	...	211
7.7	1.5	6.7	0.06	15.5	0.70		45.5	0.35	...	
40	12	43	0.1	360	14	10	184	....	....	212
2.1	7.4	2.5	0.01	21.0	0.82	0.58	10.7	....	...
17	3.5	43	0.2	210	108	None	60	18	10	213
6.6	5	2.5	0.01	12.6	6.3		3.5	1.1	0.58	
28	129	58	1.0	287	110	0.75	186	14	20	214
1.6	7.5	3.4	0.06	16.7	6.4	0.04	10.9	0.82	1.2	
1.2	9.6	167	0.1	....	112	None	186	46	None	215
0.07	0.56	9.7	0.01	....	6.5		10.9	2.7		

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
COSHOCOTON—Concluded						
216	Coshocton Straw Paper Co. Four driven wells in the gravel, one with 8-in. and three with 6-in. casings. One well yields 100,000 gal. daily. Water is softened by the Scaife continuous system. No boiler trouble.					
		Pts. per mill.	472	258	172	86
		Grs. per gal.	27.5	15.0	10.0	5.0
217	Same location as No. 216. Softened water.					
		Pts. per mill.	334	176	110	66
		Grs. per gal.	19.5	10.3	6.4	3.9
218	Mrs. Lina Davis. Farm 5 miles west of Coshocton. Driven well, 53 feet in gravel. The following curious circumstances were related concerning this well. It was sunk in 1887 and gave cool, palatable water till in February, 1914, when, following a severe wind storm, the water suddenly became warm and assumed a peculiar flat taste. No turbidity, however, accompanied this change. In the spring of 1915 another well was drilled about 50 feet from the first one. At 33 feet warm water was struck. Drilling was continued to 94 feet but water still remained warm and had a peculiar taste. Actual temperatures were not taken and in the summer of 1915 when temperature readings were directed nothing unusual was found.					
		Pts. per mill.	866	330	122 ¹¹	208
		Grs. per gal.	50.5	19.3	7.1	12.1

DAYTON

Samples collected February 8-10, 1915.

219	City water. The city water is from a large number of wells sunk into the underlying gravel and from 30 to 60 feet deep. The supply is abundant.	The city water is from a large number of wells sunk into the underlying gravel and from 30 to 60 feet deep. The supply is abundant.	Pts. per mill. Grs. per gal.	(12)
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¹¹Normal carbonate = 15 pts. per mill. or 0.88 grs. per gal.

¹²Analyses by J. W. Elms, U. S. Geol. Survey Water Supply Paper No. 259, p. 204.

GROUND WATERS OF OHIO Continued

Magnesium, Mg	Calcium, Ca	Sodium Potas- sium, Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
9.7	87	45	0.3	210	74	0.5	80	14	14	216
0.57	5.1	2.6	0.02	12.2	4.3	0.03	4.7	0.82	0.82	
7.3	58	32	0.2	134	52	None	62	16	...	217
0.43	3.4	1.9	0.01	7.8	3.0		3.6	0.93	...	
20	100	107	6.2	149	48	None	69	30	None	218
1.2	5.8	6.2	0.36	8.7	2.8		4.0	1.8		
28	52	21	....	270	11	....	53	16	....	219
1.6	3.0	1.2	....	15.8	0.6	....	3.1	0.9	...	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
DAYTON—Continued						
220	Dayton Engineering Laboratory Co., Foundry and First Sts. Drilled well, 120 feet, gravel all the way. Pumped 250 gal. per minute. Used for drinking, heating, and flushing. Graphite boiler compound employed. Reported that it prevents adhering of scale.	Pts. per mill.	354	320	302	18
		Grs. per gal.	20.6	18.7	17.6	1.1
221	National Cash Register Co., west of Main St. between canal and river. Forty-three wells from 35 to 60 feet, 8-in. casing, passing through various strata of sand, gravel, and clay. When this raw water was used in boilers it caused pitting and hard scale. It is now softened; in April 1914 the average daily amount treated was 167,400 gal. Cost of softening reported as about 2 cents per 1,000 gal.	Pts. per mill.	524	425	330	95
		Grs. per gal.	30.5	24.8	19.3	5.5
222	National Cash Register Co., east of Main St. Seven wells from 60 to 70 feet through strata of gravel, clay, hard pan, and ending in gravel.	Pts. per mill.	782	530	342	188
		Grs. per gal.	45.6	30.9	19.9	11.0
223	Speedwell Motor Co., Essex Ave. Drilled well. Excelsior boiler compound used with this water for making steam.	Pts. per mill.	360	315	270	45
		Grs. per gal.	21.0	18.4	15.8	2.6
224	Peoples Railway Co., Bohlander Ave. car barns. Drilled well, 33 feet, 8-in. casing, through gravel.	Pts. per mill.	632	435	312	123
		Grs. per gal.	36.9	25.4	18.2	7.2
225	Ohio Rake Co., Albany St. Drilled well, 85 feet, ending in rock. Pumps 60,000 gal. per day. Used in boilers with steam purifier and one quart daily of Franklin boiler compound. Boilers cleaned every three weeks. Scale does not stick.	Pts. per mill.	564	417	320	97
		Grs. per gal.	32.9	24.3	18.7	5.7

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No
30	78	11	0.76	368	8.0	None	17	10	11	220
1.8	4.6	0.64	0.04	21.5	0.47	.	0.99	0.58	0.64	
39	106	20	0.6	403	22	1.5	96	6.0	29	221
2.3	6.2	1.2	0.04	23.5	1.3	0.09	5.6	0.35	1.7	
47	134	42	0.2	417	48	34	119	10	27	222
2.7	7.8	2.5	0.01	24.3	2.8	2.0	6.9	0.58	1.6	
32	74	9.0	4.8	329	10	None	50	2.0	9.0	223
1.9	4.3	0.53	0.28	19.3	0.58		2.9	0.12	0.53	
41	106	33	0.3	381	32	26	95	16	28	224
2.4	6.2	1.9	0.02	22.2	1.9	1.5	5.5	0.93	1.6	
40	101	24	0.1	390	32	18	76	32	15	225
2.3	5.9	1.4	0.02	22.8	1.9	1.1	4.4	1.9	0.88	

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
DAYTON—Continued					
226	Beaver Soap Co., Concord and Scoville Sts. Driven well, 95 feet, 3-in. casing, in sand and gravel. Level of water 15 feet from surface. Pumps 30,000 gal. daily. Used in soap making and in boilers. Treated in 200 H. P. open heater before entering boilers. Heaters cleaned every four weeks, nearly full by this time. Boilers cleaned twice a year, blown off every two hours. Soda ash formerly used but caused trouble from foaming. Graphite used in boilers now and found very satisfactory.				
	Pts. per mill.	382	335	307	28
	Grs. per gal.	22.3	19.6	17.9	1.6
227	Aetna Paper Co., Columbia and Cincinnati Sts. Driven well, 40 feet. Ten wells, 7- and 8-in. casings, on the property, one 80 feet deep. Sample is from this well and another one of same location, 80 feet deep, to second layer of gravel. Combined pumpage, 1,500,000 gal. per 24 hours. Used for boiling rags and washing paper; also in turbine boilers along with boiler compound. Forms hard scale sticking to tubes.				
	Pts. per mill.	466	362	275	87
	Grs. per gal.	27.2	21.1	16.1	5.1
228	Reynolds & Reynolds Co., Washington and Dudley Sts. Driven well, 8-in. casing. Pumps 50 gal. per minute. Used in Sterling water tube boilers with open heater. Fifteen pounds sal soda used daily. No scale trouble.				
	Pts. per mill.	574	397	340	57
	Grs. per gal.	33.5	23.2	19.8	3.3
229	Kuhns Bros. Co., Eaton Ave. Drilled well, 94 feet in gravel.				
	Pts. per mill.	430	365	307	58
	Grs. per gal.	25.1	21.3	17.9	3.4
230	Sucher Packing Co., Western Ave. and Dakota. Drilled well, 40 feet, 6-in. casing, in gravel. Used in condensers and boilers. Softened with lime and soda ash. No scale trouble.				
	Pts. per mill.	424	355	275	80
	Grs. per gal.	24.7	20.7	16.1	4.7

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
33	80	9.0	1.3	374	12	None	22	30	9.0	226
1.9	4.7	0.53	0.08	21.8	0.70		1.3	1.8	0.53	
34	89	16	0.14	335	16	8.3	84	20	8.0	227
2.0	5.2	0.93	0.01	19.6	0.93	0.48	4.9	1.2	0.47	
39	95	47	0.12	415	40	19	72	24	20	228
2.3	5.5	2.7	0.02	24.2	2.3	1.1	4.2	1.4	1.2	
35	88	11	2.0	374	12	0.3	56	16	12	229
2.0	5.1	0.64	0.12	21.8	0.70	0.02	3.3	0.93	0.70	
34	86	42	0.6	335	12	5.8	71	22	10	230
2.0	5.0	2.5	0.04	19.6	0.70	0.34	4.1	1.3	0.58	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
DAYTON—Continued						
231	A. A. Simonds Sons Co., Summit and Naegley Place. Two wells, 52 and 90 feet, 6-in. casings, connected to one pump. Used in boilers with soda ash and graphite. Open heater also employed; but little sludge precipitated in it.	Pts. per mill.	348	295	245	50
		Grs. per gal.	20.3	17.2	14.3	2.9
232	Same location as No. 231. Well 48 feet.	Pts. per mill.	402	327	265	62
		Grs. per gal.	23.4	19.1	15.5	3.6
233	Maxwell Motor Co., Leo St. Drilled well, 55 feet, 6-in. casing. Level of water, 15 feet from surface. Pumps 100 gal. per minute. Used in Erie City and Gem City 150 H. P. fire tube boilers. Two barrels Arrow boiler compound employed in four months. Feed water entrance clogs if not closely watched. Soft scale with a little hard scale. Return water from heating system also used in boilers.	Pts. per mill.	476	370	270	100
		Grs. per gal.	27.8	21.6	15.8	5.8
234	Dayton Pipe & Coupling Co., Edmund and C. H. & D. R. R. Drilled well, 59 feet, in sand and gravel bed. Used for cooling around furnace.	Pts. per mill.	462	370	295	75
		Grs. per gal.	26.9	21.6	17.2	4.4
235	Barney & Smith Car Co., Monument and Keowee Sts. Six drilled wells, average 75 feet. Composite sample. Scales more than canal water. Used for fire protection and drinking.	Pts. per mill.	782	550	382	168
		Grs. per gal.	45.6	32.1	22.3	9.8
236	Dayton Gas Co., East Monument Ave. and St. Clair. Driven well, 60 feet, 8-in. casing, through hardpan. Copious iron precipitate in pipes.	Pts. per mill.	442	362	277	85
		Grs. per gal.	25.8	21.1	16.2	5.0
237	Reibold Bldg., Fourth and Main Sts. Drilled well, 80 feet, 8-in. casing, in gravel. Pumps 200,000 gal. per day. Used in boilers with lime and soda ash. No scale.	Pts. per mill.	478	377	312	65
		Grs. per gal.	27.9	22.0	18.1	3.8

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No
29	70	12	0.36	299	8.0	14	52	8.0	11	231
1.7	4.1	0.70	0.02	17.4	0.47	0.82	3.0	0.47	0.64	
32	79	14	0.3	323	8.0	16	57	16	14	232
1.9	4.6	0.82	0.02	18.9	0.47	0.93	3.3	0.93	0.82	
36	88	9.0	0.3	329	14	25	61	18	11	233
2.1	5.1	0.53	0.02	19.3	0.82	1.5	3.6	1.1	0.64	
36	88	16	1.3	360	10	1.0	86	20	8.0	234
2.1	5.1	0.93	0.08	21.0	0.58	0.06	5.0	1.2	0.47	
51	136	25	0.24	466	30	30	106	38	36	235
3.0	7.9	1.5	0.01	27.2	1.8	1.8	6.2	2.2	2.1	
34	89	14	0.14	338	12	7.0	71	6.0	6.0	236
2.0	5.2	0.82	0.01	19.8	0.70	0.41	4.1	0.35	0.35	
62	49	32	0.14	381	22	12	65	8.0	6.0	237
3.6	2.9	1.9	0.01	22.1	1.3	0.70	3.8	0.47	0.35	

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or tem- porary hardness, CaCO ₃	Non- carbonate or per- manent hardness, CaCO ₃
DAYTON—Concluded					
238	Brownell Co., Findlay St. Drilled well, 50 feet, 8-in. casing. Used in boiler with open heater and soda ash. Heavy precipitate in heater. Heater cleaned every two weeks. Two wagon loads mud obtained. Boilers washed down every two weeks.				
	Pts. per mill.	452	390	302	88
	Grs. per gal.	26.4	22.8	17.6	5.1
239	Dayton Manufacturing Co., Third and Garfield Sts. Driven well, 34 feet, 4-in. casing. Used in shell boiler with Arrow compound. Open heater also employed. Heavy precipitate in heater.				
	Pts. per mill.	814	525	287	238
	Grs. per gal.	47.5	30.6	16.7	13.9
240	Davis Sewing Machine Co., Davis St. and Linden Ave. Four driven wells, 35 to 40 feet, 6-in. casings. Pumps 10,000 gal. per day of 10 hrs. Use boiler compound.				
	Pts. per mill.	630	495	360	135
	Grs. per gal.	36.8	28.9	21.0	7.9
241	Excelsior Laundry Co., Sixth and Logan Sts. Driven well, 70 feet. Use 350 lbs. soda per week but no lime. Capacity of softener 15,000 gal. per hour.				
	Pts. per mill.	620	445	330	115
	Grs. per gal.	36.2	26.0	19.3	6.7
242	Schantz & Schwind Brewing Co., Foot and Perry Sts. Seven drilled wells. Composite sample from four wells, 50, 100, 50 and 60 feet. Softened with lime and soda ash.				
	Pts. per mill.	484	375	305	70
	Grs. per gal.	28.0	22.0	18.0	4.1
243	Troy Pearl Laundry Co., 32 W. Zeigler St. Drilled well, 33 feet, 8-in. casing. 75,000 gal. daily. Softened at estimated cost of 2 cents per 1,000 gal. No scale trouble in boilers.				
	Pts. per mill.	562	447	355	92
	Grs. per gal.	33.0	26.0	21.0	5.4
244	Dayton Breweries Co., Apple and Brown Sts. Two drilled wells, 70 feet, 8-in. casing. Use water softener employing lime and soda ash. Had much scale trouble before softener was put in. Open heater is used after softener.				
	Pts. per mill.	784	505	325	180
	Grs. per gal.	46.0	29.4	19.0	11.0

GROUND WATERS OF OHIO- Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No
35	58	54	0.1	368	16	8.8	73	4.0	15.0	238
2.0	3.8	3.1	0.01	21.5	0.93	0.51	4.3	0.23	0.88	
50	128	30	0.2	350	36	36.5	140	12	15	239
2.9	7.5	1.8	0.01	20.4	2.1	2.1	8.2	0.70	0.88	
45	124	24	0.15	439	26	11	114	6.0	37	240
2.6	7.2	1.4	0.01	25.6	1.5	0.64	6.6	0.35	2.2	
35	120	36	0.2	403	42	22	97	6.0	26	241
2.0	7.0	2.1	0.01	23.5	2.5	1.3	5.7	0.35	1.5	
35	92	31	0.2	372	38	8.0	68	8.0	14	242
2.0	5.4	1.8	0.01	22.0	2.2	0.46	4.0	0.46	0.81	
40	113	26	0.2	433	26	16.5	74	6.0	38	243
2.3	6.6	1.5	0.01	25.6	1.5	0.96	4.3	0.35	2.2	
45	128	47	0.4	396	50	38	110	14	26	244
2.6	7.5	2.7	0.02	23.2	2.9	2.2	6.4	0.82	1.5	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
DELAWARE						
Samples collected June 2, 1915.						
245	City water. Seventeen wells, 26 to 30 feet, in gravel; two wells, 90 feet, in limestone; and three wells, 220 feet, in porous rock. These last two wells pump 100,000 gal. each in 24 hours. The group of wells pumps 900,000 gal. daily and is located three miles north of the city.	Pts. per mill.	552	400	270	130
		Grs. per gal.	32.2	23.3	15.8	7.6
246	C. D. & M. Power Plant. Stratford, south of city. Well probably 200 feet deep. Flows naturally in wet seasons, at other times must be pumped.	Pts. per mill.	880	655	420	235
		Grs. per gal.	51.0	38.2	24.5	13.7
247	Same location as No. 246. Olentangy River water.	Pts. per mill.	478	310	212	98
		Grs. per gal.	27.9	18.1	12.4	5.7
DENNISON						
Samples collected November 11, 1915.						
248	City water supply. Stillwater Creek. Water is treated with a coagulant and filtered through a rapid sand filter. Chloride of lime is also used at times to kill bacteria. This water is likewise supplied to Uhrichsville.	Pts. per mill.	262	180	152	28
		Grs. per gal.	15.3	10.5	8.9	1.6
249	Same location as No. 248. Raw creek water. Was formerly used in boilers but gave scale.	Pts. per mill.	284	189	152	37
		Grs. per gal.	16.6	11.0	8.9	2.2
DUNDAS						
Samples collected in 1916.						
250	S. J. Benner, Lockland Farm. Pond about 3 acres in extent.	Pts. per mill.	54	16	12	4.0
		Grs. per gal.	3.2	0.93	0.70	0.23
251	Same location as No. 250. Spring.	Pts. per mill.	52	18	15	3.0
		Grs. per gal.	3.0	1.1	0.88	0.18
EAST LIVERPOOL						
	No analyses. City gets its supply from Ohio River. Wells of the neighborhood are reported hard.					
	

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
34	104	16	1.0	329	8.0	0.25	152	44	6.0	245
2.0	6.0	0.93	0.06	19.3	0.47	0.02	8.9	2.6	0.35	
59	164	20	1.9	512	6.0	0.60	246	76	65	246
3.4	9.5	1.2	0.11	29.9	0.35	0.04	14.4	4.4	3.8	
30	74	24	0.9	259	10	4.5	130	48	5.0	247
1.8	4.3	1.4	0.05	15.1	0.58	0.26	7.6	2.8	0.29	
11	54	38	0.1	185	8.0	None	62	None	6.0	248
0.64	3.2	2.2	0.01	10.9	0.47		3.6		0.35	
12	56	39	1.0	185	8.0	0.75	58	6.0	11	249
0.70	3.3	2.3	0.06	10.9	0.47	0.04	3.4	0.35	0.64	
2.4	2.4	7.0	0.8	15	6.0	None	8.4	....	....	250
0.14	0.14	0.41	0.05	0.85	0.35		0.49	....	....
2.4	3.2	7.5	0.3	18	6.0	1.5	2.0	....	....	251
0.14	0.19	0.44	0.02	1.07	0.35	0.09	0.12	....	....

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃	
EAST PALESTINE						
	No analyses. The McGraw Tire & Rubber Co. reports two wells, 200 and 250 feet, ending in sandstone, as giving a hard, slightly salt water which causes foaming. It is used for cooling. The city supply is from two drilled wells, 200 feet, and two dug wells, 20 feet, in white sandstone. Capacity of the four wells 400,000 gal. Water forms scale in boilers and foams slightly.	.....	.....	.....	.....
EATON						
	No analyses. City supply is from wells and is reported hard.	.....	.....	.....	.....
ELYRIA						
Samples collected August 24-25, 1915.						
252	City water supply. Lake Erie water purified for drinking by treating with ferrous sulfate as coagulant and filtering. The Western Automatic Screw Co. uses the city water in its boilers with Dearborn compound. Without the compound there would be scale trouble.	Pts. per mill.	172	110	85 ¹³	25
		Grs. per gal.	10.0	6.4	5.0	1.5
253	Cleveland & S. W. Power Plant. Water from W. Branch, Black River. Used in boilers with open feed water heater. Makes hard scale.	Pts. per mill.	486	250	152	98
		Grs. per gal.	28.4	14.6	8.9	5.7
254	Fox Furnace Co., Fox Ave. Water from a pond, partly surface supply and partly fed by springs. No scale trouble reported.	Pts. per mill.	226	104	90	14
		Grs. per gal.	13.2	6.1	5.3	0.82
255	Columbia Steel Co. Water from an abandoned quarry fed by springs. At time sample was taken there had been heavy rains and water was turbid. Sample was taken from discharge pipe of pump, intake being at bottom of quarry. Water is used for pickling.	Pts. per mill.	428	245	257	None
		Grs. per gal.	25.0	14.3	15.0	

¹³Normal carbonate = 10 pts. per mill. or 0.58 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
.....	
7.3	32	12	0.3	104	10	5.0	22	2.0	None	252
0.43	1.9	0.70	0.02	6.1	0.58	0.29	1.3	0.11		
20	68	33	4.2	185	12	2.0	97	26	5.0	253
1.2	4.0	1.9	0.25	10.9	0.70	0.12	5.7	1.5	0.29	
6.1	32	20	1.6	110	8.0	2.0	53	12	13	254
0.36	1.9	1.2	0.09	6.5	0.47	0.12	3.1	0.70	0.76	
23	60	52	2.0	313	16	2.5	69	22	32	255
1.3	3.5	3.0	0.12	18.3	0.92	0.15	4.0	1.3	1.8	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
ELYRIA—Concluded						
256	Same location as No. 255. Sample taken from surface of water in the quarry.	Pts. per mill.	276	156	147	9.0
		Grs. per gal.	16.1	9.1	8.6	0.53
257	Western Automatic Screw Co., Lake Ave. Drilled well, 27 feet, 12 feet in rock, 6-in. casing. Used for drinking.	Pts. per mill.	794	446	215	231
		Grs. per gal.	46.3	26.0	12.5	13.4
258	Harshaw Fuller & Goodwin Co., Center St. East Branch, Black River. Water was at high stage when sample was taken. Used in boilers with Arrow compound.	Pts. per mill.	380	171	112	59
		Grs. per gal.	22.2	10.0	6.5	3.4
259	Fire Department No. 1. Court and Second Sts. Well, 25 feet. Used for drinking.	Pts. per mill.	1144	651	435	216
		Grs. per gal.	67.0	38.0	25.3	12.6

FINDLAY

Samples collected July 22, 1915.

260	City supply. Twelve wells, 60 feet, located about 11 miles southeast of the city. A 24-in. vitrified tile conduit conveys the water to the town. Pumpage 1,500,000 gal. daily.	Pts. per mill.	388	301	250	51
		Grs. per gal.	22.7	17.5	14.6	3.0
261	Grant Motor Car Co. Drilled well, 1600 feet, is believed to end in sand. Water level 20 feet from surface. Used in boilers with closed heater. Graphite added. Hard scale forms.	Pts. per mill.	1080	529	132	397
		Grs. per gal.	63.0	30.8	7.7	23.1
262	D. Kirk Flour Mills, E. Sandusky. Eagle Creek, at flood stage. Used in boilers with Hawkeye compound.	Pts. per mill.	402	213	162	51
		Grs. per gal.	23.4	12.4	9.4	3.0
263	Adams Truck, Machine and Foundry Co. Drilled well. Used in boilers, gives much scale.	Pts. per mill.	1060	669	337	332
		Grs. per gal.	61.8	39.0	19.7	19.4

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
14.6	38	23	1.6	179	8.0	None	48	24	11	256
0.85	2.2	1.3	0.09	10.5	0.47		2.8	1.4	0.64	
36	118	36	6.4	262	16.0	None	189	16	75	257
2.1	6.8	2.1	0.37	15.3	0.93		11.0	0.93	4.4	
15	44	22	3.8	137	8.0	1.0	61	58	5.0	258
0.88	2.6	1.3	0.22	7.9	0.47	0.06	3.6	3.4	0.29	
79	130	97	0.6	531	90	15	236	22	32	259
4.6	7.6	5.7	0.04	30.9	5.3	0.88	13.8	1.3	1.9	
30	70	11	0.2	305	4.0	15	56	8.0	12	260
1.8	4.1	0.63	0.01	17.8	0.23	0.88	3.3	0.47	0.70	
64	106	110	0.3	161	14	None	402	24	4.0	261
3.7	6.2	6.4	0.02	9.4	0.82		23.4	1.4	0.23	
18	55	24	3.6	198	4.0	16	53	62	5.0	262
1.1	3.2	1.4	0.21	11.5	0.23	0.93	3.1	3.6	0.29	
64	162	45	0.3	411	72	1.3	241	28	35	263
3.7	9.4	2.6	0.02	24.0	4.2	0.08	14.1	1.6	2.0	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or tem- porary hardness, CaCO ₃	Non- carbonate or per- manent hardness, CaCO ₃
FINDLAY—Concluded						
264	National Refining Co., West Lima St. Five drilled wells, 250 feet, into lime- stone. Contains some hydrogen sulfide. Wells were originally 100 feet deep and went dry when heavy pumping from sugar factory near by began. Used in boilers, gives hard scale.	Pts. per mill.	762	499	302	197
		Grs. per gal.	44.4	29.1	17.6	11.5
265	Continental Sugar Co., West Park. Drilled well, 25 feet, into limestone. Gives much scale in boiler.	Pts. per mill.	476	358	277	81
		Grs. per gal.	27.8	20.9	16.2	4.7
266	Krantz Brewing Co. Drilled well, 150 feet, 6-in. casing. Was originally a gas well. Used for cooling and condensing.	Pts. per mill.	1350	504	252	252
		Grs. per gal.	79.0	29.4	14.7	14.7
FOSTORIA						
Samples collected July 26, 1915.						
267	City water. Water is from Portage River filtered through a slow sand filter. The T. F. & F. R. R. Co. uses this water in its boilers and reports that it gives very little scale and sludge.	Pts. per mill.	264	136	122	14
		Grs. per gal.	15.4	8.0	7.1	0.82
268	Toledo, Fostoria & Findlay R. R. Co. Drilled well, 85 feet, 45 feet in lime- stone, 5-in. casing. Was tried in boilers but gave too much scale and sludge.	Pts. per mill.	1512	862	167	695
		Grs. per gal.	88.2	50.3	9.7	40.6
269	Harter Milling Co., Findlay Road. Well, in the rock.	Pts. per mill.	1462	814	125	689
		Grs. per gal.	85.0	47.5	7.3	40.2
270	Fostoria Ice & Coal Co., E. North St. Drilled well, 70 feet, to the rock. Water level 8 feet from surface. Softened with lime and soda ash. System is a con- tinuous one depending entirely on set- tling to give clear water. Used in boil- ers gives very little soft scale.	Pts. per mill.	1280	748	202	546
		Grs. per gal.	74.7	43.6	11.8	31.8

GROUND WATERS OF OHIO--Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
52	114	29	0.2	368	38	1.0	182	16	22	264
3.0	6.6	1.7	0.01	21.5	2.2	0.06	10.6	0.93	1.3	
41	75	25	0.2	338	8.0	4.5	91	None	18	265
2.4	4.4	1.5	0.01	19.8	0.47	0.26	5.3		1.1	
51	118	217	0.8	307	372	None	183	26	47	266
3.0	6.9	12.7	0.05	17.9	21.7		10.7	1.5	2.7	
4.9	46	30	1.4	149	6.0	16	47	12	4.0	267
0.29	2.7	1.8	0.08	8.7	0.35	0.93	2.7	0.70	0.23	
89	199	96	1.8	204	20	1.0	600	24	8.0	268
5.2	11.6	5.6	0.11	11.8	1.2	0.06	35.0	1.4	0.47	
73	206	98	1.8	152	22	None	572	10	10	269
4.3	12.0	5.7	0.11	8.9	1.3		33.4	0.58	0.58	
74	177	96	2.0	246	20	0.5	512	30	22	270
4.3	10.3	5.6	0.12	14.4	1.2	0.03	29.9	1.8	1.3	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
FOSTORIA—Concluded						
271	National Carbon Co., Town and Tiffin Sts. Drilled well, 200 feet, 8-in. casing. Water level 10 feet from surface. Has pumped 2,000 gal. per day. Softened by "American" system with caustic soda and soda ash. This softened water in boilers gives very little trouble. The raw water gave much scale and also caused foaming and priming.	Pts. per mill.	1602	869	175	694
		Grs. per gal.	93.4	50.7	10.2	40.5
272	Peabody Vehicle Co., W. Union St. Drilled well, 99 feet, 87 feet in rock, 4-in. casing. Water level 16 feet from surface. Pumpage 5,500 gal. per 10 hours. Used in return tubular boilers with potatoes, $\frac{1}{2}$ bu. every two weeks. Water is fed by injector which clogs up with scale and must be cleaned every 3 days. Before using the potatoes more scale trouble was experienced. The potatoes are reported "to prevent scale to some extent and keep loose that which does form."	Pts. per mill.	498	333	245	88
		Grs. per gal.	29.0	19.4	14.3	5.1
FREMONT						
Samples collected February, 1916.						
273	Fremont Grape Juice Co., 319 Concord Place. Well, 178 feet. Causes scale in boilers.	Pts. per mill.	466	369	332	37
		Grs. per gal.	27.2	21.5	19.4	2.2
274	Fremont Simple Account Sales Book Co., corner Jackson and Napoleon Sts. Wells, 135 feet. Causes scale in boilers.	Pts. per mill.	444	324	340	None
		Grs. per gal.	25.9	18.9	19.8	
275	Henkel Manufacturing Co., 223 Prospect Place. Well, 93 feet. Causes scale in boilers.	Pts. per mill.	1730	1080	192	888
		Grs. per gal.	101.0	63.0	11.2	51.8
276	Fremont Brewing Co., 436 N. Clover St. Well, 100 feet. Causes scale in boilers.	Pts. per mill.	454	370	322	48
		Grs. per gal.	26.5	21.6	18.8	2.8

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
84	210	78	2.2	213	28	1.4	572	32	12	271
4.9	12.3	4.6	0.13	12.4	1.6	0.08	33.4	1.9	0.70	
36	73	4.0	0.16	299	10	35	58	38	15	272
2.1	4.3	0.23	0.01	17.4	0.58	2.0	3.4	2.2	0.88	
35	90	25	0.5	405	6.0	1.7	65	....	25	273
2.0	5.3	1.5	0.03	23.7	0.35	0.10	3.8	....	1.5	
46	54	42	0.3	415	4.0	3.5	48	....	21	274
2.7	3.2	2.5	0.02	24.2	0.23	0.20	2.8	....	1.2	
92	280	52	1.6	234	18	0.5	882	....	20	275
5.4	16.3	3.0	0.09	13.7	1.1	0.03	51.4	....	1.2	
34	92	23	0.7	393	6.0	0.25	63	....	22	276
2.0	5.4	1.3	0.04	22.9	0.35	0.02	3.7	....	1.3	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
FREMONT—Concluded						
277	Trommer Extract of Malt Co., 121 S. Arch St. Well, 57 feet. Causes scale in boilers.	Pts. per mill.	868	516	400	116
		Grs. per gal.	50.6	30.1	23.3	6.8
278	Ohio Light & Power Co., 922 Garrison St. Well, 160 feet. Causes scale in boilers.	Pts. per mill.	492	394	332	62
		Grs. per gal.	28.7	23.0	19.4	3.6
GALION						
Samples collected September 24, 1915.						
279	City water. Eight driven wells, 65 feet, 6- and 8-in. casings. Used in boilers with open heater and "Pearline" and graphite. Not much sludge in heater. Scale in boilers easily removed.	Pts. per mill.	1216	870	370	500
		Grs. per gal.	70.9	50.7	21.6	29.2
280	Galion Brewing Co., Lincoln Way, West Galion. Drilled well, 107 feet, 8-in. casing. Pumps 12,000 barrels daily. Used in boilers with soda. Scale does not stick to tubes.	Pts. per mill.	486	263	312	None
		Grs. per gal.	28.4	15.3	18.1	
281	Galion Lumber Co., S. Market and Big Four R. R. Drilled well, 90 feet, 4-in. casing. Pumps 1,600 gal. daily. Used in boiler with heater and Arrow compound. No scale trouble. Heater removes much scale.	Pts. per mill.	830	601	382	219
		Grs. per gal.	48.4	35.0	22.3	12.7
282	Peoples Pure Ice Co., Heidelberg St. Well, "at least 160 feet deep," 6-in. casing. Used in condensers and boilers. Hard scale forms on condensers. Graphite is used in boilers.	Pts. per mill.	572	274	382	None
		Grs. per gal.	33.4	16.0	22.3	
283	E. M. Freese & Co., South St. Well, 80 feet, 4-in. casing. Mixed with rain water is used in boilers. Gives hard scale.	Pts. per mill.	1242	830	375	455
		Grs. per gal.	72.5	48.4	21.9	26.6
GALLOWAY						
Sample collected summer of 1915.						
284	Helen M. Abbot, R. F. D. No. 1, well.	Pts. per mill.	510	440	345 ¹⁴	95
		Grs. per gal.	29.8	25.7	20.1	5.5

¹⁴Normal carbonate = 25 pts. per mill. or 1.5 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
53	118	111	0.6	488	128	3.0	119	....	70	277
3.1	6.9	6.5	0.04	28.4	7.5	0.18	6.9	....	4.1	
36	98	23	0.4	405	6.0	0.8	78	....	29	278
2.1	5.7	1.3	0.02	23.7	0.35	0.05	4.6	....	1.7	
61	248	47	0.16	451	22	7.5	390	....	54	279
3.6	14.5	2.7	0.01	26.4	1.3	0.44	22.8	....	3.1	
30	55	71	0.9	381	8.0	1.0	90	36	21	280
1.8	3.2	4.1	0.05	22.1	0.47	0.06	5.3	2.1	1.2	
52	154	26	0.3	466	18	1.5	189	12	Acid	281
3.0	8.9	1.5	0.02	27.2	1.1	0.09	10.9	0.70		
46	34	109	0.3	466	6.0	2.2	100	28	21	282
2.7	2.0	6.4	0.02	27.2	0.35	0.13	5.8	1.6	1.2	
63	228	52	1.2	457	12	None	396	20	33	283
3.7	13.3	3.0	0.07	26.7	0.70		23.1	1.2	1.9	
44	104	16	0.4	421	10	1.5	72	36	None	284
2.6	6.1	0.93	0.02	24.5	0.58	0.09	4.2	2.1		

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
GIRARD						
Sample collected summer of 1915.						
285	Albert A. Miller, well, 35 feet, in shale.	} Pts. per mill. } Grs. per gal.	4848 283.0	2487 145.0	520 30.0	1967 115.0
HAMILTON						
Samples collected April 5-6, 1915.						
286	City water. Twenty wells, 100 feet, 6-in. casings, and 2 wells, 100 feet, 8-in. casings. All pumped together.	} Pts. per mill. } Grs. per gal.	414 24.1	332 19.4	285 16.6	47 2.7
287	Hoover Owens & Rintschler Co., Fourth and Heaton Sts. Drilled well, 44 feet, 3-in. casing, in gravel. Supply is cut down by pumping at other plants. Used for drinking.	} Pts. per mill. } Grs. per gal.	524 30.5	407 23.7	315 18.4	92 5.4
288	Same location as No. 287. Two wells, 70 feet, 8-in. casings, ending in gravel. Used in condensers. Was tried in boilers but gave scale trouble.	} Pts. per mill. } Grs. per gal.	454 26.5	382 22.3	301 17.6	81 4.7
289	Beckett Paper Co., Fourth and Buckeye Sts. Ten driven wells, 70 to 108 feet, 5- to 10-in. casings, in gravel. Pumpage 2,500,000 gal. daily. Softened with lime and soda ash by We-fu-go system.	} Pts. per mill. } Grs. per gal.	420 24.5	365 21.3	305 17.8	60 3.5
290	Black-Clawson Co., Second and Vine Sts. Drilled well, 59 feet, 8-in. casing, in gravel. Water level 30 feet from surface. Used in boiler with open feed water heater. Electric compound employed. Some hard scale.	} Pts. per mill. } Grs. per gal.	422 24.6	347 20.2	302 17.6	45 2.6
291	Niles Tool Works Co., Third and Mill Sts. Three drilled wells, 45 feet, 8-in. casings, in gravel. Used for drinking.	} Pts. per mill. } Grs. per gal.	584 34.0	472 27.5	367 21.4	105 6.1
292	Same location as No. 291. River water which enters town through a race and is used in boliers by several plants.	} Pts. per mill. } Grs. per gal.	390 22.8	307 17.9	222 12.9	85 5.0

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
367 21.4	391 22.9	304 17.7	0.3 0.02	634 36.6	68 4.0	0.25 0.01	1890 110.0	12 0.7	91 5.3	285
29 1.7	85 5.0	23 1.3	7.4 0.43	348 20.3	8.0 0.47	1.0 0.06	54 3.2	14 0.82	11 0.64	286
41 2.4	95 5.5	25 1.5	0.3 0.02	384 22.4	22 1.3	2.3 0.13	96 5.6	14 0.82	15 0.88	287
35 2.0	95 5.5	11 0.64	0.4 0.02	367 21.5	16 0.93	2.0 0.12	71 4.1	28 1.6	15 0.88	288
32 1.9	94 5.5	8.1 0.47	0.4 0.02	372 21.7	12 0.70	5.5 0.32	62 3.6	18 1.1	19 1.1	289
37 2.2	77 4.5	18 1.1	0.3 0.02	368 21.5	10 0.58	5.5 0.32	67 3.9	24 1.4	18 1.1	290
44 2.6	117 6.8	21 1.2	0.2 0.01	448 26.1	20 1.2	7.0 0.41	98 5.7	18 1.1	34 2.0	291
27 1.6	79 4.6	10 0.58	1.8 0.11	271 15.7	8.0 0.47	8.5 0.50	56 3.3	18 1.1	None	292

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
HAMILTON—Continued						
293	Champion Coated Paper Co., B. St. Five drilled wells, 100 feet, 8-in. casings. Pumpage 4,000 gal. per min. for 24 hrs. Softened by We-fu-go system with lime. A little soft scale in boilers. Dearborn compound used in addition to softening. Reported trouble from pitting when soda ash was used. Open heater also employed.					
		Pts. per mill.	394	330	267	63
		Grs. per gal.	23.0	19.3	15.6	3.7
294	Mason Brewing Co., South C. St. Two drilled wells, 110 and 118 feet, 8-in. casings. Pumpage 10,000 gal. per day. Used in condensers and boilers. Hawk-eye compound employed, Hoppes open heater. Hard scale forms.					
		Pts. per mill.	640	457	375	82
		Grs. per gal.	37.3	26.7	21.9	4.8
295	Shuler & Bennighofen, Lindenwald. Drilled well, 60 feet, ending in gravel. Used for drinking.					
		Pts. per mill.	372	317	285	32
		Grs. per gal.	21.7	18.5	16.6	1.9
296	Same location as No. 295. Erie Canal water. Used in boilers after softening with lime and soda ash, Kennicott system. Preheated in closed heater.					
		Pts. per mill.	384	310	222 ¹⁵	88
		Grs. per gal.	22.4	18.1	12.9	5.1
297	Hamilton Tool Co., Lindenwald. Driven well, 60 feet, 6-in. casing, in gravel. Used in boiler with open heater gave scale trouble.					
		Pts. per mill.	392	315	250	65
		Grs. per gal.	22.9	18.4	14.6	3.8
298	H. P. Deuscher Co., Hanover and Seventh Sts. Driven well, 60 feet, 3-in. casing. Used for drinking.					
		Pts. per mill.	514	385	302	83
		Grs. per gal.	30.0	22.5	17.6	4.8
299	Estate Stove Co., East Ave. Two driven wells, 60 feet, 5- and 6-in. casings. Pump 50,000 gal. daily. Used in boilers with open heater. Dearborn compound employed. Compound was changed three times. Water seemed to be changing. Without compound hard scale is given. Compound softens it.					
		Pts. per mill.	418	360	292	68
		Grs. per gal.	24.4	21.0	17.0	4.0

¹⁵Normal carbonate = 15 pts. per mill. or 0.88 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
30	82	15	0.5	326	10	1.8	60	18	7.0	293
1.8	4.8	0.76	0.02	19.0	0.58	0.11	3.5	1.1	0.41	
36	123	42	1.0	457	50	25	60	20	19	294
2.1	7.2	2.5	0.06	26.7	2.9	1.5	3.5	1.2	1.1	
27	83	8.0	0.24	348	20	0.5	24	24	7.0	295
1.6	4.8	0.47	0.01	20.3	1.2	0.03	1.4	1.4	0.41	
30	74	11	0.24	271	8.0	8.0	53	10	None	296
1.8	4.3	0.64	0.01	15.7	0.47	0.47	3.1	0.58		
28	80	4.5	0.34	305	10	16.5	47	38	11	297
1.6	4.7	0.26	0.02	17.8	0.58	0.96	2.7	2.2	0.64	
34	98	22	0.6	368	22	27	64	8.0	19	298
2.0	5.7	1.3	0.04	21.5	1.3	1.6	3.7	0.47	1.1	
33	90	10	0.2	356	12	5.8	56	38	13	299
1.9	5.3	0.58	0.01	20.7	0.70	0.34	3.3	2.2	0.76	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
HAMILTON—Concluded						
300	Mosler Safe Co., Grand Boulevard. Two drilled wells, 90 feet, 6- and 8-in. casings, in gravel. Pump 50,000 gal. daily. Softened by We-fu-go system for use in boilers.	Pts. per mill.	670	445	307	138
		Grs. per gal.	39.1	26.0	17.9	8.0
301	Herring-Hall-Marvin Safe Co., Grand Boulevard. Driven well, 80 feet, 6-in. casing. Used in boilers with Hawkeye compound. Forms hard scale. Water seems to change with change of seasons; was analyzed three times by Dearborn Chemical Co. and found to vary in composition.	Pts. per mill.	684	442	310	132
		Grs. per gal.	39.9	25.8	18.1	7.7
302	Cincinnati Brewing Co., Front and Sycamore Sts. Four driven wells, 78 to 118 feet, 10-in. casings. Pump 1,000,000 gal. daily. Used in boilers after softening with lime and soda ash with We-fu-go system. No scale trouble.	Pts. per mill.	494	345	275 ¹⁶	70
		Grs. per gal.	28.8	20.1	16.1	4.1
JACKSON						
Samples collected January 26, 1916.						
303	City water. Eleven drilled wells, 150 feet, 8-in. casings, situated 6 miles south of city. Pump 250,000 gal. daily. In the city itself salt water is encountered at 150 to 160 feet.	Pts. per mill.	316	184	155	29
		Grs. per gal.	18.4	10.7	9.0	1.7
304	D. T. & I. Shops. Drilled well, 55 feet, 3-in. casing, in rock. Mixed with creek water is used in boilers. Gives little scale, is called good boiler water.	Pts. per mill.	528	109	132	None
		Grs. per gal.	30.8	6.4	7.7	
KENTON						
Sample taken March, 1915.						
305	Hardin-Wyandot Lighting Co. Pond fed by springs. Used in boiler with soda ash. This pond water is reported much better than the company's well water.	Pts. per mill.	438	268	107 ¹⁷	161
		Grs. per gal.	25.5	15.6	6.2	9.4

¹⁶Normal carbonate = 12 pts. per mill. or 0.70 grs. per gal.¹⁷Normal carbonate = 10 pts. per mill. or 0.58 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg.	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
36	118	22	0.26	374	28	35	82	44	24	300
2.1	6.9	1.3	0.02	21.8	1.6	2.0	4.8	2.6	1.4	
39	113	29	0.24	378	40	35	76	56	17	301
2.3	6.6	1.7	0.01	22.1	2.3	2.0	4.4	3.3	0.99	
33	84	33	0.3	335	32	12	53	24	None	302
1.9	4.9	1.9	0.02	19.6	1.9	0.70	3.1	1.4		
22	38	42	3.4	189	28	1.5	60	....	28	303
1.3	2.2	2.5	0.20	11.0	1.6	0.09	3.5	....	1.6	
11	26	158	5.8	161	196	None	36.6	....	30	304
0.64	1.5	9.2	0.34	9.4	11.4		2.1	....	1.8	
34	51	35	0.2	130	38	13	111	....	None	305
2.0	3.0	2.0	0.01	7.6	2.2	0.76	6.5	....	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
LANCASTER						
Samples collected June 28, 1915.						
306	City water. Six driven wells, 97 to 107 feet, 8- and 6-in. casings. Pump 1,000,000 gal. daily. Used in boilers with graphite; scale is loose.	Pts. per mill.	396	335	300	35
		Grs. per gal.	23.1	19.6	17.5	2.0
307	Lancaster Glass Works, S. Ewing St. Drilled well, 60 feet, 4-in. casing, ending in gravel. Used for drinking.	Pts. per mill.	360	245	187	58
		Grs. per gal.	21.0	14.3	10.9	3.4
308	Crystal Ice Co., Locust St. Driven wells, 30 feet, 6-in. casings, in gravel. Pump 90 gal. per min. Used in boilers with open heater. Soda ash is fed into pump line. Graphite had been used but without success.	Pts. per mill.	454	305	237	68
		Grs. per gal.	26.5	17.8	13.8	4.0
309	Ohio Shoe Co., well 105 feet, 8-in. casing, in gravel. Used for drinking and cooling.	Pts. per mill.	534	385	300	85
		Grs. per gal.	31.1	22.4	17.5	5.0
310	Hocking Glass Co., West Side. Driven well, 24 feet, in gravel. Used for drinking and cooling.	Pts. per mill.	452	305	232	73
		Grs. per gal.	26.4	17.8	13.5	4.3
311	E. Becker Brewing Co., 302 Union St. Two drilled wells, 95 feet, 8-in. casings, in gravel. Water level 20 feet from surface. Pump 180 gal. per min. Used in boilers with open heater. Much sludge in heater. Graphite was used but with little success.	Pts. per mill.	388	305	257	48
		Grs. per gal.	22.6	17.8	15.0	2.8
312	Same location as No. 311. Drilled well, 50 feet, 6-in. casing, in gravel. Used for cooling.	Pts. per mill.	1410	525	385	140
		Grs. per gal.	82.0	30.6	22.5	8.2
313	Boys Industrial Home, six miles south of Lancaster. Six wells, 400 feet, 6-in. casing. Pump 11,000 gal. per day. Used in boilers where it gives very little scale, about $\frac{1}{64}$ in. in a year. Water in neighboring localities reported soft.	Pts. per mill.	64	41	40	1.0
		Grs. per gal.	3.7	2.4	2.3	0.06

GROUND WATERS OF OHIO Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
30	82	11	1.9	306	12	1.1	41	30	9.0	306
1.7	4.8	0.64	0.11	21.4	0.70	0.06	2.4	1.8	0.53	
22	62	9.0	0.4	228	8.0	6.0	62	26	4.0	307
1.3	3.6	0.53	0.02	13.3	0.47	0.35	3.6	1.5	0.23	
27	78	14	0.6	289	22	3.0	71	48	8.0	308
1.6	4.6	0.82	0.04	16.8	1.3	0.18	4.1	2.8	0.47	
34	98	15	2.4	366	28	None	68	34	21	309
2.0	5.7	0.87	0.14	21.4	1.6		4.0	2.0	1.2	
28	76	15	0.3	283	8.0	24	60	26	7.0	310
1.6	4.4	0.88	0.02	16.5	0.47	1.4	3.5	1.5	0.41	
25	80	11	2.2	313	14	None	48	28	14	311
1.5	4.7	0.64	0.13	18.3	0.82		2.8	1.6	0.82	
42	140	285	0.4	470	420	24	85	None	42	312
2.5	8.2	16.6	0.02	27.5	24.5	1.4	5.0		2.5	
4.9	8.4	3.6	0.26	49	4.0	None	1.0	12	1.0	313
0.29	0.49	0.21	0.02	2.8	0.23		0.06	0.70	0.06	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
LIMA						
Samples collected July 27, 1915.						
314	City water. Supply is taken from the Ottawa River from which it is pumped into a large reservoir and flows by gravity into two smaller reservoirs from which in turn it is pumped into the mains. 3,500,000 gal. daily are used. Is used, by a number of firms, in boilers, after softening. Preferred to well water.	Pts. per mill.	506	256	140	116
		Grs. per gal.	29.5	14.9	8.2	6.8
315	Lima Locomotive Works. Drilled well, 300 feet, 8-in. casing. Water level 90 feet from surface. 12,000 gal. per hour pumped. Contains hydrogen sulfide. Used for hydraulic testing.	Pts. per mill.	1202	644	305	339
		Grs. per gal.	70.1	37.6	17.8	19.8
316	Solar Refining Co., Nos. 20 and 21 of a group of 21 wells. "Sulphur" vein struck at 180 feet. Water level 90 feet from surface. Used for cooling and condensing. Supply is 200,000 gal. daily.	Pts. per mill.	868	526	315	211
		Grs. per gal.	50.6	30.7	18.4	12.3
317	Same location as No. 316. Well No. 3, 380 feet. Water struck at 160 feet. At first the water level was 46 feet from surface but later dropped to 67 feet. Contains hydrogen sulfide.	Pts. per mill.	1356	719	320	399
		Grs. per gal.	79.1	41.9	18.7	23.3
318	Same location as No. 316. Softened Ottawa River water. Softening was done with lime and soda ash. Following experience reported: when softening was carried to about 51 parts per million (3 grains per gal.) of total hardness, there was trouble from foaming. When, however, the water was left with about 84 parts per mill. (5 grains per gal.) of hardness no such trouble was experienced. See No. 319 for raw water.	Pts. per mill.	268	67	2.0 ¹⁸	65
		Grs. per gal.	15.6	3.9	0.12	3.8
319	Same location as No. 316. River water pumped into large reservoir, the pumping always being done in rainy seasons. Hardness of raw water reported pretty constant.	Pts. per mill.	362	184	97	87
		Grs. per gal.	21.1	10.7	5.7	5.1

¹⁸Normal carbonate = 65 pts. per mill. or 3.8 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
21	68	24	0.3	171	42	13	78	24	7.0	314
1.2	4.0	1.4	0.18	10.0	2.5	0.76	4.6	1.4	0.41	
74	136	84	0.2	372	50	None	378	66.0	40	315
4.3	7.9	4.9	0.01	21.7	2.9		22.0	3.9	2.3	
61	110	58	0.2	384	22	None	267	42	35	316
3.0	6.4	3.4	0.01	22.4	1.3		15.6	2.5	2.0	
84	150	101	0.2	390	84	None	360	68	14	317
4.9	8.8	5.9	0.01	22.8	4.9		21.0	4.0	0.82	
9.7	10.8	58	0.12	2.0	34	8.5	80	20	None	318
0.57	0.63	3.4	0.01	0.15	2.0	0.50	4.7	1.2		
16	48	22	0.6	118	32	10	68	8.0	1.0	319
0.93	2.8	1.3	0.04	7.0	1.9	0.58	4.0	0.47	0.06	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or tem- porary hardness, CaCO ₃	Non- carbonate or per- manent hardness, CaCO ₃
LIMA—Continued						
320	Lima Packing Co., S. Central Ave. Drilled well, 265 feet, 18 feet to rock. Water level 45 feet from surface. Used in condensers and boilers. Boilers have feed water heaters. Not much scale or sludge found in heaters. Hard scale and mud in boilers.	Pts. per mill.	1344	719	312	407
		Grs. per gal.	78.4	41.9	18.2	23.7
321	Same location as No. 320. Drilled well, 150 feet, 8-in. casing. Contains hydrogen sulfide. Used in condensers and boilers mixed with water from No. 320. In the condensers and water lines pipes are badly pitted and trouble is experienced in the filling up of the feed lines.	Pts. per mill.	1328	719	312	407
		Grs. per gal.	77.4	41.9	18.2	23.7
322	Mosier Laundry Co., 221 N. Central Ave. Well used for drinking.	Pts. per mill.	1344	839	385	454
		Grs. per gal.	78.4	48.9	22.5	26.5
323	Lima Brewing Co., E. Pennsylvania Ave. Drilled well, 154 feet, 8-in. casing, 15 feet to rock. Water level 60 feet from surface. Contains hydrogen sulfide. Is called "white sulphur" water. Cold water corrodes feed lines. Used in boilers with feed water heater, and graphite to keep scale from sticking. Boiler is not corroded.	Pts. per mill.	1126	593	285	308
		Grs. per gal.	65.6	34.6	16.6	18.0
324	Crystal Ice & Coal Co., N. McDonald St. and Pennsylvania R. R. Two drilled wells, 380 feet, 8-in. casings, 65 feet to rock, water level 90 feet from surface. Pumpage 300 gal. per min. for 24 hrs. Contains hydrogen sulfide. At 165 feet a vein of "black sulphur" water was struck. This attacked the pipes. Present water is called "white sulphur" and does not corrode the pipes. (Note: This behavior of "white sulphur" water is contrary to that recorded under No. 323.) The water was tried in boilers but scaled them too rapidly.	Pts. per mill.	1570	785	290	495
		Grs. per gal.	91.6	45.8	16.9	28.9

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
80	156	98	0.8	381	116	None	440	28	45	320
4.7	9.1	5.7	0.05	22.2	6.8		25.7	1.6	2.6	
78	160	89	0.4	381	108	None	404	18	41	321
4.6	9.3	5.2	0.02	22.2	6.3		23.6	1.1	2.4	
100	172	83	1.4	470	56	0.8	456	26	37	322
5.8	10.0	4.8	0.08	27.5	3.3	0.05	26.6	1.5	2.2	
63	133	84	3.6	348	92	1.3	285	28	24	323
3.7	7.8	4.9	0.21	20.3	5.4	0.08	16.6	1.6	1.4	
101	148	150	1.0	354	22	None	480	60	31	324
5.9	8.6	8.8	0.06	20.6	1.3		28.0	3.5	1.8	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
LIMA—Concluded						
325	Lima Ice & Coal Co., N. Elizabeth St. and Pennsylvania R. R. Drilled well, 384 feet, into rock. Is called a "white sulphur" water. Is said to attack pipes. Used for cooling and condensing.	Pts. per mill.	1700	899	335	564
		Grs. per gal.	99.2	52.4	19.6	32.9
LOGAN						
Samples collected January 24, 1916.						
326	City water. Two dug wells, 30 feet, in gravel, bricked up and covered.	Pts. per mill.	462	377	280	97
		Grs. per gal.	26.9	22.0	16.3	5.7
327	City water. Five drilled wells, 133 feet, through rock and into gravel. Pumpage for 1915, 690,000 gal. per day.	Pts. per mill.	296	225	177	48
		Grs. per gal.	17.3	13.1	10.3	2.8
328	City Water Works. Hocking River at high stage. Used in boilers with open feed water heater which removes much sludge. Hawkeye compound used in boilers. Some priming noticed. The well waters above gave more hard scale than the river water.	Pts. per mill.	222	109	72	37
		Grs. per gal.	12.9	6.3	4.2	2.2
329	Logan Pottery Co. Driven well, 60 to 70 feet, 6-in. casings, through rock to water stratum. Not able to pump it dry. Used in boilers with feed water heater. No scale trouble. One boiler in use for 13 years without replacing a tube.	Pts. per mill.	318	220	242	None
		Grs. per gal.	18.5	12.8	14.1	
330	Crystal Ice Co. Spring coming out of a hillside. Used in boiler with closed heater. No scale trouble.	Pts. per mill.	240	132	67	65
		Grs. per gal.	14.0	7.7	3.9	3.8
LORAIN						
Samples collected August 24, 1915.						
331	City water. Lake Erie water filtered through rapid sand filter after sedimentation. Aluminum sulfate used as coagulant. Used in boilers with Peerless compound. Not much scale trouble. Reported that when lime and iron sulfate were used as coagulant not so much scale was formed.	Pts. per mill.	160	102	87	15
		Grs. per gal.	9.3	5.9	5.1	0.88

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
102	192	101	1.4	409	124	None	492	42	47	325
5.9	11.2	5.9	0.08	23.9	7.2		28.7	2.5	2.7	
30	101	17	1.6	342	22	None	88	....	45	326
1.8	5.9	0.99	0.09	19.9	1.3		5.1	....	2.6	
18	60	19	0.3	216	30	None	48	....	15	327
1.1	3.5	1.1	0.02	12.6	1.8		2.8	....	0.88	
11	26	28	2.4	88	10	3.0	34	....	9.0	328
0.64	1.5	1.6	0.14	5.1	0.58	0.18	2.0	....	0.53	
22	52	42	0.2	295	30	0.25	19.4	....	32	329
1.3	3.0	2.5	0.01	17.2	1.8	0.01	1.1	....	1.9	
9.7	37	15	0.10	82	18	45	14.4	....	35	330
0.57	2.2	0.88	0.01	4.8	1.1	2.6	0.83	....	2.0	
6.1	31	11	0.2	106	8.0	0.4	26	None	4.0	331
0.36	1.8	0.64	0.01	6.2	0.47	0.02	1.5		0.23	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
LORAIN—Concluded						
332	Same as No. 331. Raw Lake Erie water.	Pts. per mill.	162	97	92 ¹⁹	5.0
		Grs. per gal.	9.4	5.7	5.4	0.29
333	National Tube Co., South Lorain. Black River water softened by We-fu-go system. A little scale and sometimes some pitting are reported.	Pts. per mill.	310	37	42 ²⁰	None
		Grs. per gal.	18.1	2.2	2.5	
334	Same location as No. 333. River water mixed with returned condensate water that has been softened.	Pts. per mill.	408	193	117	76
		Grs. per gal.	23.8	11.3	6.8	4.4
335	Same location as No. 333. Raw water from Black River.	Pts. per mill.	456	214	140	74
		Grs. per gal.	26.6	12.5	8.2	4.3
MANSFIELD						
Samples collected August 27, 1915.						
336	City water, Oak St. Four wells, 160 to 180 feet, 10-in. casings. Pump 700,000 gal. daily.	Pts. per mill.	360	270	240	30
		Grs. per gal.	21.0	15.8	14.0	1.8
337	City water, N. Main St. Drilled well, 125 feet, 10-in. casing, in gravel. Pump 250 gal. per min. Used in boilers with open feed water heater. Much sludge in heater. Arrow compound in boiler. Some scale forms.	Pts. per mill.	576	412	290	122
		Grs. per gal.	33.6	24.0	16.9	7.1
338	City water, Longview. Four wells in gravel. Pump 2,000,000 gal. daily.	Pts. per mill.	418	315	242	73
		Grs. per gal.	24.4	18.4	14.0	4.3
339	Barnes Manufacturing Co., N. Main St. Rocky Fork Creek. Water was high. Used in boilers with soda ash.	Pts. per mill.	2080	300	None	300
		Grs. per gal.	121.0	17.0		17.0
340	Mansfield Tire & Rubber Co., Newman St. Drilled well, 285 feet, 6-in. casing. Rock struck at 50 feet. Used in boilers without treatment. No scale whatever. Boilers ran three and a half years without cleaning.	Pts. per mill.	558	180	307	None
		Grs. per gal.	32.5	10.5	17.9	

¹⁹Normal carbonate = 7 pts. per mill. or 0.40 grs. per gal.²⁰Normal carbonate = 40 pts. per mill. or 2.3 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
6.1 0.36	29 1.7	17 0.99	0.6 0.04	112 6.6	10 0.58	0.7 0.04	22 1.3	8.0 0.47	None	332
4.9 0.29	6.8 0.40	85 5.0	1.4 0.08	51 3.1	18 1.1	4.0 0.23	100 5.8	4.0 0.23	None	333
15 0.88	53 3.1	34 2.0	1.8 0.11	143 8.3	18 1.1	2.5 0.15	89 5.2	2.0 0.12	10 0.06	334
17 0.99	58 3.4	37 2.2	3.2 0.19	171 10.0	14 0.82	2.5 0.15	93 5.4	6.0 0.35	9.0 0.53	335
23 1.3	76 4.1	16 0.93	0.4 0.02	293 17.1	10 0.58	6.0 0.35	57 3.3	16 0.93	32 1.8	336
35 2.0	107 6.2	23 1.3	0.64 0.04	354 20.6	16 0.92	None	136 7.9	26 1.5	21 1.2	337
28 1.6	80 4.7	13 0.76	0.4 0.02	295 17.1	8.0 0.47	4.0 0.23	96 5.6	18 1.1	38 2.2	338
22 1.3	84 4.9	None	284 16.5	None	.... ....	.... ....	.... ....	21 1.2	Acid to methyl orange	339
20 1.2	40 2.3	141 8.2	0.3 0.02	374 21.8	64 3.7	2.5 0.15	79 4.6	20 1.2	7.0 0.41	340

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
MANSFIELD—Concluded						
341	Renner & Weber Brewing Co., Temple Court. Drilled well, 250 feet, 10-in. casing. Water level 15 feet from surface. Used in boilers with graphite to keep scale loose. Trouble in pipe line from condensers clogging.	Pts. per mill.	416	288	230	58
		Grs. per gal.	24.3	17.0	13.4	3.4
342	Baxter Stove Co., E. Fifth St. Drilled well, 240 feet, 6-in. casing, into gravel. Water level 21 feet from surface. Used in boilers at one time, gave very little scale trouble.	Pts. per mill.	372	267	297	None
		Grs. per gal.	21.7	15.5	17.3	
343	Humphreys Manufacturing Co., E. Fifth St. Drilled well, 800 feet, though pumping is done from 250-foot level where casing had burst. In gravel. Used in boilers with Arrow compound. Not much scale and what forms does not stick.	Pts. per mill.	392	289	292	None
		Grs. per gal.	22.9	16.8	17.0	
344	Julius Weber Ice Co., Wayne St. Drilled well, 69 feet, 6-in. casing. Water level 22 feet from surface. Used in boilers with graphite. Scale keeps loose. Open heater takes out considerable sludge.	Pts. per mill.	590	438	292	146
		Grs. per gal.	34.4	25.5	17.0	8.5
345	Ohio Brass Co., Pennsylvania and Erie crossing. Drilled well, 536 feet, 10-in. casing, 75 feet to rock. Well used to flow but now water level is 25 feet from surface, goes down to 150 feet when pumping. Used in boilers with soda ash. No scale. An open heater removes some sludge.	Pts. per mill.	834	205	275	None
		Grs. per gal.	48.6	12.0	16.0	
MARION						
Samples collected June 24, 1915.						
346	City water, E. Center St. Fifteen wells, 140 to 200 feet, 6- to 10-in. casings. Pump 1,750,000 gal. daily. One report received that the city water is hard on brass and plumbing.	Pts. per mill.	956	615	315	300
		Grs. per gal.	56.0	35.9	18.4	17.5

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium , Potassium, Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
26	73	25	0.4	281	22	14	66	20	42	341
1.5	4.3	1.5	0.02	16.3	1.3	0.81	4.0	1.2	2.5	
28	61	33	1.8	362	8.0	0.6	44	20	9.0	342
1.6	3.6	1.9	0.11	21.1	0.47	0.04	2.6	1.2	0.53	
28	70	29	4.6	356	16	0.5	47	24	17	343
1.6	4.1	1.7	0.27	20.7	0.93	0.03	2.7	1.4	0.99	
39	111	17	2.4	356	32	0.5	118	24	9.0	344
2.3	6.5	0.99	0.14	20.7	1.9	0.03	6.9	1.4	0.53	
23	44	239	0.6	335	276	2.0	49	18	7.0	345
1.3	2.6	13.9	0.04	19.5	16.1	0.12	2.9	1.1	0.41	
47	168	43	1.0	384	8.0	0.9	270	84	2.0	346
2.7	9.8	2.5	0.06	22.4	0.47	0.05	15.8	4.9	0.11	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
MARION—Continued						
347	Marion Ice & Cold Storage Co., Oak St. and Big Four R. R. Three wells, 200 feet, 10-in. casings, limestone struck at 20 feet, slate at 185 feet. Water level 90 feet from surface when pumping. Pump 600 gal. per min. Used in boilers after softening with lime and soda ash by We-fu-go system. Soft scale only. Boilers ran three months without cleaning and 23 years without removing tubes.	Pts. per mill.	608	465	380	85
		Grs. per gal.	35.5	27.1	22.2	5.0
348	Same location as No. 347. Softened water.	Pts. per mill.	360	39	7 ²¹	32
		Grs. per gal.	21.0	2.3	0.41	1.9
349	Hocking Valley R. R. Softening plant.	Pts. per mill.	....	92	(²²)	92
		Grs. per gal.	....	5.4	....	5.4
350	C. D. & M. Light Department, N. High St. and Big Four R. R. Well, 114 feet, 10-in. casing. Rock at 10 feet from surface. Water level 25 feet from surface. Pumps 20,000 gal. per day. Used in boilers and condensers after softening with lime and soda ash. Good water in boiler, but causes scale in the brass tubes ($\frac{5}{8}$ in. diam.) of the condensers. Untreated water was worse.	Pts. per mill.	926	605	387	218
		Grs. per gal.	54.0	35.3	22.5	12.7
351	Same location as No. 350. Treated water. Trouble reported in the settling of the softened water; requires from 12 to 24 hours.	Pts. per mill.	718	182	70 ²³	112
		Grs. per gal.	41.9	10.6	4.1	6.5
352	Huber Manufacturing Co., N. Greenwood St. Two wells, 140 feet, 8-in. casings, rock at 10 feet. Water level 30 feet from surface. Contains hydrogen sulfide. Used in boilers with Hoppes live steam purifier. Had used Mexican graphite but quit. Some hard scale.	Pts. per mill.	740	500	340	160
		Grs. per gal.	43.1	29.2	19.8	9.3

²¹Normal carbonate = 155 pts. per mill. or 9.0 grs. per gal.²²Normal carbonate = 50 pts. per mill. or 2.9 grs. per gal.

Hydroxide = 22 pts. per mill. or 1.3 grs. per gal.

²³Normal carbonate = 270 pts. per mill. or 15.8 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
39	122	21	0.7	464	22	0.25	101	40	34	347
2.3	7.1	1.2	0.04	27.1	1.3	0.02	5.9	2.3	2.0	
7.3	3.6	118	0.3	8.0	26	None	103	62	None	348
0.43	0.21	6.9	0.02	0.50	1.5		6.0	3.6		
9.7	21	....	....	....	....	....	....	....	....	349
0.57	1.2	....	....	....	....	....	....	....	....
47	164	33	2.4	472	50	None	173	52	30	350
2.7	9.5	1.9	0.14	27.5	2.9		10.1	3.0	1.8	
42	2.8	203	0.14	85	52	None	202	34	None	351
2.5	0.16	11.9	0.01	5.0	3.0		11.8	2.0		
45	126	16	0.30	415	22	None	160	54	10	352
2.6	7.4	0.93	0.02	24.2	1.3		9.3	3.2	0.58	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
MARION—Concluded						
353	Same location as No. 352. Well located about 100 yards from No. 352. Contains hydrogen sulfide.	Pts. per mill.	748	490	320	170
		Grs. per gal.	43.5	28.6	18.7	9.9
354	Susquehanna Silk Mills. Well, 125 feet, 6-in. casing, 14 feet to rock. Water level 15 feet from surface. Has 150,000 gal. cistern for collecting rain water. Use well water when this supply runs low. Franklin compound and graphite used to prevent scale from sticking.	Pts. per mill.	476	410	365	45
		Grs. per gal.	27.8	23.9	21.3	2.6
355	Marion Steam Shovel Co., W. Center St. and Railroad. Two wells, 240 feet, 8-in. casings. Pump 50,000 gal. daily. Used in boilers with Cochran open heaters. Lime and soda ash are fed into water before entering heaters. There is some hard scale. Graphite is used and appears to help in preventing scale from sticking.	Pts. per mill.	728	522	357	165
		Grs. per gal.	42.5	30.4	20.8	9.6
356	Same location as No. 355. Well 165 feet, 8-in. casing. Used in boilers along with water from well No. 355.	Pts. per mill.	716	517	372	145
		Grs. per gal.	41.8	30.1	21.7	8.4
357	Marion Brewing Co., Bellefontaine Ave. Two wells, 125 feet, 10-in. casings. Rock at 30 feet. Used in boilers after softening with lime and soda ash by We-fu-go system.	Pts. per mill.	1222	813	422	385
		Grs. per gal.	71.0	47.4	24.6	22.4
MARTINS FERRY						
358	City water. Twenty-nine wells driven along the shore of the Ohio River. Average depth 32 feet, in gravel. Capacity 5,000,000 gal. daily.	Pts. per mill.	328	204	100	104
		Grs. per gal.	19.1	11.9	5.8	6.1
359	Belmont Brewing Co. well.	Pts. per mill.	930	594	237	357
		Grs. per gal.	54.3	34.6	13.8	20.8

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium Potassium, Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
42	126	23	0.6	390	40	None	150	20	30	353
2.5	7.4	1.3	0.04	22.8	2.3		8.8	1.2	1.8	
35	106	6.0	1.7	445	8.0	None	41	62	33	354
2.0	6.2	0.35	0.10	26.0	0.47		2.4	3.6	1.9	
45	135	17	1.4	435	10	0.75	192	80	39	355
2.6	7.9	0.99	0.01	25.4	0.58	0.04	11.2	4.7	2.3	
49	128	17	3.6	454	16	None	157	104	42	356
2.9	7.5	0.99	0.21	26.5	0.93		9.2	6.0	2.5	
84	187	34	4.0	515	8.0	1.1	402	140	63	357
4.9	10.9	2.0	0.23	30.0	0.47	0.06	23.4	8.2	3.7	
12	62	24	0.1	122	20	1.2	93	....	6	358
0.7	3.6	1.4	0.01	7.1	1.2	0.07	5.4	....	0.35	
32	186	49	0.44	289	44	15	329	....	15	359
1.9	10.9	2.9	0.03	16.8	2.6	0.88	19.2	....	0.88	

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃	
MARYSVILLE						
360	Reformatory for Women. Two wells, 260 feet, 10-in. casings. Each well has been pumped at the rate of 6,000 gal. per hour without affecting supply. Water is reported to pit all iron with which it comes into contact. A paint made from crude oil and graphite and applied to the inside of the boilers is said to eliminate this pitting.	Pts. per mill.	1768	1113	290	823
		Grs. per gal.	103.0	65.0	16.9	48.0
361	Same location as No. 360. Water after softening with lime and soda ash in a Booth Softener. Experience with softened water given as most satisfactory.	Pts. per mill.	1456	64.0	(²⁴)	64
		Grs. per gal.	86.0	3.7		3.7
MASSILLON						
Samples collected October 12-13, 1915.						
362	City water. Ten wells, 250 feet, 6-in. casings, ending in sand rock. Pump 800,000 gal. daily. Used in boilers with compound gives no scale trouble.	Pts. per mill.	356	303	230	73
		Grs. per gal.	20.8	17.7	13.4	4.3
363	Massillon Rolling Mill Co. Six driven wells, 100 feet, 8- to 12-in. casings. Supply of water sufficient for boilers. Before using in boilers it is softened with lime and soda ash by We-fu-go system.	Pts. per mill.	1194	803	275	528
		Grs. per gal.	69.6	46.9	16.0	30.8
364	Same location as No. 363. Five driven wells, 175 to 220 feet, 6-in. casings. Sample is from one of the 220-foot wells. For use in boilers this water is softened with lime and soda ash by We-fu-go system. No scale trouble since softening. Before softening the water caused much hard scale and corrosion around gaskets and threads.	Pts. per mill.	286	209	172 ²⁵	37
		Grs. per gal.	16.7	12.1	10.0	2.2

²⁴Normal carbonate = 70 pts. per mill. or 4.1 grs. per gal.
Hydroxide = 20 pts. per mill. or 1.2 grs. per gal.

²⁵Normal carbonate = 5 pts. per mill. or 0.29 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium Potassium, Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
123	243	69	4.2	354	10	None	853	....	25	360
7.2	14.2	4.0	0.25	20.6	0.58		49.7	....	1.5	
7.3	13.6	449	0.16	....	12	None	877	....	None	361
0.43	0.79	26.2	0.01	....	0.70		51.2	....	
24	81	4.2	0.6	281	12	None	66	10	12	362
1.4	4.7	0.24	0.04	16.3	0.70		3.9	0.58	0.70	
54	231	27	1.7	335	122	0.5	306	16	49	363
5.2	13.5	1.6	0.99	19.5	7.1	0.03	17.9	0.93	2.9	
17	56	16	0.2	210	8.0	6.5	60	12	None	364
0.99	3.3	0.93	0.01	12.2	0.47	0.38	3.5	0.70		

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
MASSILLON—Concluded						
365	Same location as No. 363. Softened water from group of wells described under No. 364. Company has calculated cost of softening per ton of their product, steel, and give it as 3½ cents.	Pts. per mill.	256	84	(²⁶)	84
		Grs. per gal.	14.9	4.9	....	4.9
366	Stark-Tuscarawas Brewing Co., Schuster Branch, West St. and Canal. Five driven wells, 114 feet, 4-in. casings, in gravel. Water level 8 feet from surface, drops to 22 feet when pumping. Wells can be pumped at rate of 200 gal. per minute. Used for brewing and in boilers. Dearborn compound used in boilers. Open feed water heater also used.	Pts. per mill.	312	268	212	56
		Grs. per gal.	18.2	15.6	12.4	3.3
367	Artificial Ice & Coal Co., N. Erie St. Driven well, 25 feet, 12-in. casing. Forms hard scale in boilers. Report that graphite and compounds were tried but gave no help.	Pts. per mill.	496	377	257	120
		Grs. per gal.	28.9	22.0	15.0	7.0
368	Russell & Co., S. Erie St. Drilled well, 160 feet, 3-in. casing. Used for drinking.	Pts. per mill.	303	274	237	37
		Grs. per gal.	17.7	16.0	13.8	2.2

MEDINA

Samples collected in spring of 1916.

369	The A. J. Root Co., Champion Brook. A dam holds a supply. In summer when water is low and probably is largely spring water, some scale forms. In other seasons water is fair.	Pts. per mill.	156	115	62	53
		Grs. per gal.	9.1	6.7	3.6	3.1
370	Same location as No. 369. Well, 160 feet, into rock. This water was tried in the boilers but caused pitting.	Pts. per mill.	2208	422	290	132
		Grs. per gal.	129.0	24.6	16.9	7.7

²⁶Normal carbonate = 40 pts. per mill. or 2.3 grs. per gal.
Hydroxide = 60 pts. per mill. or 3.5 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
12.2	13.6	51	0.6	....	12	8.0	60	34	None	365
0.71	0.79	3.0	0.04	....	0.70	0.47	3.5	2.0		
20	75	2.0	0.5	259	16	None	55	14	8.0	366
1.2	4.4	0.12	0.03	15.1	0.93		3.2	0.82	0.47	
29	103	15	0.4	313	40	13	96	18	18	367
1.7	6.0	0.88	0.02	18.3	2.3	0.76	5.6	1.1	1.1	
23	72	2.0	0.22	289	6.0	0.5	36	19	7.0	368
1.3	4.2	0.12	0.01	16.8	0.35	0.03	2.1	1.1	0.41	
16 5	20	None	1.4	76	6.0	7.0	51	....	....	369
0.93	1.2		0.08	4.4	0.35	0.41	3.0	....	....
49	89	576	0.6	354	204	None	1023	....	....	370
2.9	5.2	33.6	0.04	20.6	11.9		59.6	....	....

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃	
MT. GILEAD (No analyses)						
	City water is from wells, 80 feet, ending in gravel. Water level 6 feet from surface. This is lowered to 20 feet by pumping at rate of 3,500 gal. per hour. In boilers a hard scale forms.					
MT. VERNON						
Samples collected November 8, 1915.						
371	City water. Eleven drilled wells, 80 feet, through hard pan into gravel, flowing. One dug well, 14 feet, 12 feet in diameter, in gravel. Amount 1,250,000 gal. per day. Used in boilers forms soft scale. Graphite loosens up scale that would otherwise be hard.	Pts. per mill. Grs. per gal.	358 20.9	300 17.5	295 17.2	5.0 0.29
372	Mt. Vernon Ice Delivery Co. Nine wells, 58 to 60 feet, in sand and gravel, flowing wells. Used in boilers forms soft scale. Compound used. In ice making the salts in this water concentrate in core. Practice is to freeze till cake is nearly solid when the interior water is drawn off and the space filled with distilled water and the freezing continued.	Pts. per mill. Grs. per gal.	352 20.5	302 17.6	300 17.5	2.0 0.12
373	Pittsburgh Plate Glass Co. Dug well, 18 feet, 14 feet in diameter. Has been pumped at rate of 1,000 gal. per min., without affecting supply. Some trouble from scale. Use Imperial boiler coating to prevent scale from adhering.	Pts. per mill. Grs. per gal.	356 20.8	288 16.8	230 13.4	58 3.4
374	Same location as No. 373. Four artesian wells, 75 to 85 feet, located in swamp. Tried in boilers but caused corrosion.	Pts. per mill. Grs. per gal.	324 18.9	267 15.6	287 16.7	None
375	Hope Forge & Machine Co. Two wells, 25 feet, 5-in. casings. Used for cooling and flushing.	Pts. per mill. Grs. per gal.	356 20.8	316 18.4	275 16.1	41 2.4

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
28	74	19	2.6	360	8.0	0.8	27	12	11	371
1.6	4.3	1.1	0.15	21.0	0.47	0.05	1.6	0.7	0.64	
28	75	17	1.2	366	4.0	0.25	21	12	12	372
1.6	4.4	0.99	0.07	21.4	0.23	0.02	1.2	0.70	0.70	
23	77	12	0.1	281	10	6.5	57	14	9.0	373
1.3	4.5	0.70	0.01	16.3	0.58	0.38	3.3	0.82	0.53	
26	65	23	2.0	350	None	0.25	14	14	10	374
1.5	3.8	1.3	0.12	20.4		0.02	0.82	0.82	0.58	
27	82	6.0	0.2	335	8.0	5.0	48	18	21	375
1.6	4.8	0.35	0.01	19.6	0.47	0.29	2.8	1.1	1.2	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
NEWARK						
Samples collected April 12-13, 1915.						
376	City water. Water from a gravel bed in north fork of Licking River. A perforated suction line extends into this gravel bar and lies 10 feet below the normal level of the river. Pumpage 5,000,000 gal. per day. Used in boilers with compound. Open heater also used. Some soft scale formed.	Pts. per mill.	326	240	185 ²⁷	55
		Grs. per gal.	19.0	14.0	10.8	3.2
377	Advance Glass Co. Drilled well, 61 feet, ending in rock. Used for condensing.	Pts. per mill.	366	305	270	35
		Grs. per gal.	21.4	17.8	15.8	2.0
378	The Wehrle Co., Union & Wilson Sts. Ohio Canal water. Used in boiler connected with closed heater. Dearborn compound employed. See No. 381.	Pts. per mill.	152	97	77 ²⁸	20
		Grs. per gal.	9.0	5.7	4.5	1.2
379	Same location as No. 378. Well, 63 feet. Used for drinking.	Pts. per mill.	408	312	305 ²⁸	7.0
		Grs. per gal.	23.8	18.2	17.8	0.41
380	Same location as No. 378. Well, 57 feet. Used for drinking.	Pts. per mill.	410	307	287 ²⁹	20
		Grs. per gal.	23.9	17.9	16.7	1.2
381	Licking Laundry Co., Jefferson St. and Raccoon Creek. Driven well, 25 feet, in gravel. Used for drinking. Ohio Canal water used in laundry. It gives no trouble.	Pts. per mill.	850	607	392	215
		Grs. per gal.	49.6	35.4	22.9	12.6
382	Consumers Brewing Co., First and Locust Sts. Two drilled wells, 130 feet, 8-in. casings, in sand and gravel. Used in boilers with open heater. A little soda ash employed. Some soft scale forms.	Pts. per mill.	332	270	250	20
		Grs. per gal.	19.4	15.8	14.6	1.2

²⁷Normal carbonate = 10 pts. per mill. or 0.58 grs. per gal.²⁸Normal carbonate = 5 pts. per mill. or 0.29 grs. per gal.²⁹Normal carbonate = 15 pts. per mill. or 0.88 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
1.0	64	13	0.26	226	8.0	1.3	53	22	None	376
1.1	3.7	0.76	0.02	13.2	0.47	0.08	3.1	1.3		
27	78	15.5	3.0	329	6.0	None	48	30	13	377
1.0	4.6	0.96	0.18	19.3	0.35		2.8	1.8	0.76	
7.3	27	7.0	0.6	94	6.0	None	23	6.0	None	378
0.43	1.0	0.41	0.04	5.5	0.35		1.3	0.35		
28	79	39	2.6	372	8.0	None	50	18	None	379
1.0	4.6	2.3	0.15	21.7	0.47		2.9	1.1		
28	77	34	3.6	350	8.0	0.25	50	44	None	380
1.0	4.5	2.0	0.21	20.4	0.47	0.02	2.9	2.6		
44	171	34	1.0	478	32	8.5	163	22	50	381
2.0	10.0	2.0	0.06	27.9	1.9	0.50	9.5	1.3	2.9	
21	74	13	2.3	305	8.0	None	27	38	5.0	382
1.2	4.3	0.76	0.13	17.8	0.47	-	1.6	2.2	0.29	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
NEWARK—Concluded						
383	Newark Ice and Cold Storage Co., Clinton St. & B. & O. R. R. Two drilled wells, 65 feet, 4-in. casings. Used in ammonia condensers. Was tried in boilers but city water was found preferable.	Pts. per mill.	330	265	200 ³⁰	65
		Grs. per gal.	19.3	15.5	11.7	3.8
384	American Bottle Co., Case Ave. Two drilled wells, 150 feet, 4-in. casings, in gravel. Rock is struck at 300 feet in this locality. Used for drinking.	Pts. per mill.	306	260	232	28
		Grs. per gal.	17.9	15.2	13.5	1.6
385	Same location as No. 384. North fork of Licking River. Used in boilers and gas engines. Some soft scale. When graphite was used in water, boilers ran for 6 years without renewing tubes.	Pts. per mill.	616	272	222 ³⁰	50
		Grs. per gal.	35.9	15.9	12.9	2.9
386	E. T. Rugg & Co. Driven well, 20 feet. Used in boilers with compound. Some scale.	Pts. per mill.	580	437	275	162
		Grs. per gal.	33.8	25.5	16.1	9.4
387	Same location as No. 386. Drilled well, 78 feet, in gravel. Used for cooling engines and for drinking.	Pts. per mill.	570	447	315	132
		Grs. per gal.	33.3	26.1	18.4	7.7
388	A. H. Heisey & Co., Oakwood Ave. Spring back in hills, water being piped to plant. Not used in boilers.	Pts. per mill.	300	270	245	25
		Grs. per gal.	17.5	15.8	14.3	1.5

NEW PHILADELPHIA

Samples collected November 12, 1915.

389	City water. Twenty-five driven wells, 50 to 90 feet, 6-in. casings, in gravel. Pump 1,500,000 gal. per day. Not so good in boilers as Tuscarawas River water.	Pts. per mill.	496	352	207	145
		Grs. per gal.	28.9	20.5	12.1	8.5

³⁰Normal carbonate = 10 pts. per mill. or 0.58 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
21	72	9.0	0.2	244	8.0	1.0	56	34	None	383
1.2	4.2	0.53	0.01	14.3	0.47	0.06	3.3	2.0		
22	68	8.0	1.0	283	6.0	0.75	33	36	3.0	384
1.3	4.0	0.47	0.06	16.5	0.35	0.04	1.9	2.1	0.18	
26	67	82	8.0	271	22	9.0	76	124	None	385
1.5	3.9	4.8	0.47	15.7	1.3	0.53	4.4	7.2		
38	113	13	0.7	335	14	1.3	130	46	16	386
2.2	6.6	0.76	0.04	19.6	0.82	0.08	7.6	2.7	0.93	
37	119	17	4.0	384	8.0	None	118	30	16	387
2.2	6.9	0.99	0.23	22.4	0.47		6.9	1.8	0.93	
25	74	None	1.6	299	8.0	0.6	26	12	4.0	388
1.3	4.3		0.09	17.4	0.47	0.04	1.5	0.70	0.23	
24	101	34	0.9	252	48	1.8	106	2.0	10	389
1.4	5.9	2.0	0.05	14.8	2.8	0.11	6.2	0.12	0.58	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
NEW PHILADELPHIA—Concluded						
390	Stark-Tuscarawas Brewing Co., S. Broadway. Two drilled wells, 80 and 100 feet, 6-in. casings, in gravel. Used for brewing and in boilers. An open heater removes a great deal of sludge. With compound very little scale trouble.	Pts. per mill.	608	354	195	159
		Grs. per gal.	35.5	20.6	11.3	9.2
391	Belmont Stamping & Enameling Co., N. Eighth St. Drilled well, 81 feet, 6-in. casing, in gravel. Used in boilers. No scale trouble reported.	Pts. per mill.	340	278	212	66
		Grs. per gal.	19.8	16.2	12.4	3.9
392	Wise-Harold Electric Co., Ray St. Drilled well, 60 feet, 3-in. casing, to rock. Boring goes through rock into gravel. Used for drinking and plating.	Pts. per mill.	346	270	187	83
		Grs. per gal.	20.2	15.8	10.9	4.8
NILES						
Samples collected October 5-6, 1915.						
393	City water. Mahoning River. Water is filtered by rapid sand filter using alum as coagulant. Pump 1,000,000 gal. daily. Gives some scale in boilers.	Pts. per mill.	278	170	90	80
		Grs. per gal.	16.2	9.9	5.3	4.7
394	City water. Raw water from Mahoning River. Sample taken above steel mills.	Pts. per mill.	290	181	90	91
		Grs. per gal.	16.9	10.6	5.3	5.4
395	Niles Glass Factory, N. Main St. and Eaton Ave. Two drilled wells, 100 feet, 4-in. casings, 50 feet into shale. Supply is constant. Used for drinking.	Pts. per mill.	938	226	247	None
		Grs. per gal.	54.7	13.2	14.4	
396	Harris Automatic Press Co., N. Main St. and Erie R. R. Drilled well, 60 feet, 5-in. casing, ends in rock. Feed water heater removes some sludge. Boiler compound used but no effect reported. Not much scale.	Pts. per mill.	658	166	320	None
		Grs. per gal.	38.4	9.7	18.7	
397	Standard Boiler & Plate Iron Co., B. & O. R. R. Drilled well, 111 feet, 6-in. casing. Pumps 10,000 gal. daily. Used for drinking.	Pts. per mill.	338	228	295	None
		Grs. per gal.	19.7	13.3	17.2	

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium Potas- sium, Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
23	104	72	0.3	238	114	None	94	14	9.0	390
1.3	6.1	4.2	0.02	13.8	6.6		5.5	0.82	0.53	
20	79	4.0	0.1	259	8.0	4.5	66	18	7.0	391
1.2	4.6	0.23	0.01	15.1	0.47	0.26	3.9	1.1	0.41	
18	78	4.0	0.2	228	8.0	3.8	81	18	10	392
1.1	4.6	0.23	0.01	13.3	0.47	0.22	4.7	1.1	0.58	
13.4	46	15	0.3	110	14	1.5	105	4.0	12	393
0.78	2.7	0.88	0.02	6.5	0.82	0.08	6.1	0.23	0.70	
16	46	13	2.6	110	16	2.0	106	8.0	18	394
0.93	2.7	0.76	0.15	6.5	0.93	0.12	6.2	0.47	1.1	
21	56	253	1.1	301	236	None	141	24	67	395
1.2	3.3	14.8	0.06	17.6	13.8		8.2	1.4	3.9	
17	38	179	1.6	390	88	None	89	20	28	396
0.99	2.2	10.4	0.09	22.8	5.1		5.2	1.2	1.6	
28	45	44	0.5	360	24	None	None	20	10	397
1.6	2.6	2.6	0.03	21.0	1.4			1.2	0.58	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
NILES—Concluded						
398	Niles Car & Manufacturing Co., Erie St. and Erie R. R. Drilled well, 100 feet, 4-in. casing, ends in white sandstone. Rock is struck at about 20 feet. Supply is not sufficient for boilers. Deficiency is made up with city water. Hard scale forms.	Pts. per mill.	654	200	225	None
		Grs. per gal.	38.1	11.7	13.1	
NORWALK (No analyses)						
	City supply is from a reservoir fed by spring and rain. Water is hard and forms scale in boilers.	.....	.....	.....	.....	.....
ORLAND						
Sample collected August, 1915.						
399	Spring in Washington Township, Hocking Co., on farm of Howard R. Lane.	Pts. per mill.	766	459	170	289
		Grs. per gal.	44.7	26.8	9.9	16.9
ORRVILLE						
Samples collected in March, 1916.						
400	City water. Supply is from wells, some in rock and some in gravel. Forms scale in boilers.	Pts. per mill.	328	272	250	22
		Grs. per gal.	19.1	15.9	14.6	1.3
401	J. M. Smucker. Drilled well.	Pts. per mill.	292	236	222	14
		Grs. per gal.	17.0	13.8	12.9	0.82
PAINESVILLE						
Samples collected October 1, 1915.						
402	City water. Lake Erie water purified by rapid sand filtration with alum as coagulant. Most manufacturers use the city supply for steam making.	Pts. per mill.	196	117	100	17
		Grs. per gal.	11.4	6.8	5.8	0.99

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium Potassium, Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
18	50	156	2.0	274	98	2.0	122	20	42	398
1.1	2.9	9.1	0.12	16.0	5.7	0.12	7.1	1.2	2.5	
.....	
40	114	42	3.5	297	6.0	1.3	256	18	80	399
2.5	4.6	2.5	0.20	12.1	0.35	0.08	14.9	1.1	4.7	
24	69	12.3	0.4	305	12	0.8	38	.....	10	400
1.4	4.0	0.72	0.02	17.8	0.70	0.05	2.2	.....	0.58	
24	54	19	0.7	271	14	1.0	30	.....	11	401
1.4	3.2	1.1	0.04	15.7	0.82	0.06	1.8	.....	0.64	
9.7	35	10	1.2	122	14	0.25	15	12	2.0	402
0.57	2.0	0.58	0.07	7.1	0.82	0.02	0.88	0.70	0.12	

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃	
PAINESVILLE—Concluded						
403	Painesville Artificial Ice Co., Liberty St. and Nickel Plate R. R. Nine dug wells, 16 to 20 feet, 8 feet in diameter. Pumpage 55,000 gal. per 24 hrs. Used in boilers after going over condensers. Pearlina compound employed. Trouble from water filling pipes after passing condensers.	Pts. per mill.	524	297	210	87
		Grs. per gal.	30.6	17.3	12.3	5.1
404	F. W. Harrison & Son. Dug well, 14 feet, 8 feet in diameter. Used in boilers with Pearlina compound. Keeps scale loose.	Pts. per mill.	380	186	145	41
		Grs. per gal.	22.2	10.9	8.4	2.4

PAULDING (No analyses)

The German-American Sugar Co. reports that it uses the water from Flat Rock Creek, when flow is sufficient, both for boilers and in extracting sugar beets. When the creek fails water is obtained from drilled wells of 600 to 800 feet in depth. The company has 17 such wells and uses an average of 11 of them. Each well gives about 170,000 gal. per 24 hrs. This well water is very hard and causes heavy and hard scale in the boilers. It is also not desirable for sugar extraction since all impurities must be removed and there are sugar losses at each point where such removals are made.

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PEORIA

Sample collected April 27, 1916.

405	Farmlands Co. Drilled well, 180 feet, 4-in. casing to rock. Rock at 60 feet. Used for drinking. Other wells in the vicinity not over 60 feet deep give a much softer water, about 80 parts per million total hardness.	Pts. per mill.	2656	1594	472	1122
		Grs. per gal.	155.0	93.0	27.5	65.4

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium and Potas- sium, Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No
29	77	41	2.8	256	18	0.25	167	36	9.0	403
1.5	4.5	2.4	0.16	15.0	1.1	0.02	9.7	2.1	0.53	
19	48	57	1.4	177	10	None	100	28	8.0	404
0.83	2.8	2.2	0.08	10.2	0.58		5.8	1.6	0.47	
...	
226	266	91	6.4	576	12	1.0	1213	....	....	405
13.2	15.5	5.3	0.37	33.6	0.70	0.06	71.0	....	....

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
PIQUA						
Samples taken in March, 1916.						
406	City water. An impounded surface supply. Sample sent by Wood Shovel & Tool Co. This water is muddy during several months of the year and gives much trouble in boilers where it forms hard scale.	Pts. per mill.	300	245	192	53
		Grs. per gal.	17.5	14.3	11.2	3.1
407	City water. Sample sent by Piqua Hosiery Co. This company softens the water with Permutite. See following numbers.	Pts. per mill.	346	280	217	63
		Grs. per gal.	20.2	16.3	12.7	3.7
408	Piqua Hosiery Co. Sample is city water No. 407 treated with alum and filtered.	Pts. per mill.	350	273	167	106
		Grs. per gal.	20.4	15.8	9.7	6.2
409	Same location as No. 407. Sample is the filtered water—No. 408—after passing through the Permutite softener. This sample was taken immediately following regeneration of the Permutite.	Pts. per mill.	386	10.0	212	None
		Grs. per gal.	22.5	0.58	12.4	
410	Same location as No. 407. Sample is the average softened water.	Pts. per mill.	406	15	212	None
		Grs. per gal.	23.7	0.88	12.4	
411	Same location as No. 407. Sample was taken just before regeneration of the Permutite.	Pts. per mill.	388	30	215	None
		Grs. per gal.	22.6	1.8	12.5	
412	Favorite Stove & Range Co. Another sample of the city water. Used in boilers with Stoddard compound. This company also uses the water for washing nickel work and reports that at certain seasons when there is a large quantity of leaves in it the water has a tendency to stain the nickel.	Pts. per mill.	382	284	225	59
		Grs. per gal.	22.3	16.6	13.1	3.4
413	Orr Felt & Blanket Co., Miami River water.	Pts. per mill.	346	270	210	60
		Grs. per gal.	20.2	15.8	12.3	3.5

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
23	6.1	5.5	0.8	234	8.0	6.0	51	....	Acid	406
1.3	3.5	0.32	0.05	13.7	0.47	0.35	3.0	....	
27	6.8	9.4	0.9	265	8.0	11	56	....	5.0	407
1.5	4.0	0.55	0.05	15.5	0.47	0.64	3.3	....	0.29	
23	7.1	7.1	0.4	204	10	14	94	....	37	408
1.3	4.1	0.41	0.02	11.8	0.58	0.82	5.5	....	2.2	
2.4	None	135	0.1	259	14	11	66	....	5.0	409
0.14		7.8	0.01	15.1	0.82	0.64	3.9	....	0.29	
3.6 0.21	None	142 8.3	0.1 0.01	259 15.1	24 1.4	11 0.64	73 4.3	.... ....	4.0 0.23	410
7.3 0.43	None	128 7.5	0.2 0.01	262 15.3	12 0.70	11 0.64	75 4.4	.... ....	3.0 0.18	411
27	7.0	39	3.8	274	6.0	None	51	....	60	412
1.6	4.1	2.3	0.22	16.0	0.35		3.0	....	3.5	
24 1.4	6.8 4.0	10 0.58	0.7 0.04	256 15.0	6.0 0.35	5.5 0.32	52 3.0	.... ....	9.0 0.53	413

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
PIQUA—Concluded						
414	Same location as No. 413. River water after softening in Dodge softener. This water is used for wool scouring, dyeing, and washing blankets and felts. It is reported very satisfactory.	Pts. per mill.	178	93	(³¹)	93
		Grs. per gal.	10.4	5.4	....	5.4
SALEM						
Samples collected October 8, 1915.						
415	City water. Seventeen drilled wells, average depth 205 feet, 8-in. casings, to rock struck at 90 feet. Pump 800,000 gal. daily. Used in boilers with graphite gives some hard scale.	Pts. per mill.	330	269	240	29
		Grs. per gal.	19.3	15.7	14.0	1.7
416	W. H. Mullin Co. Drilled wells, 312 feet, 3-in. casings. Run dry sometimes in summer. Used in boilers leaves sludge but no hard scale. An open feed water heater does not remove much sludge.	Pts. per mill.	384	116	260	None
		Grs. per gal.	22.4	6.8	15.2	
417	Same location as No. 416. Drilled well, 490 feet, 3-in. casing. Salt water was struck but was cased off. Used for flushing.	Pts. per mill.	898	60	255	None
		Grs. per gal.	52.4	3.5	14.9	
418	Silver Manufacturing Co., Broadway and Perry Sts. Two drilled wells, 95 feet, 6- and 8-in. casings. Rock struck at 20 feet. Pump 50,000 gal. daily. Used in boilers and for cooling. Forms hard scale, difficult to remove, in the boilers.	Pts. per mill.	634	451	247	204
		Grs. per gal.	37.0	26.4	14.4	11.9
419	American Steel & Wire Co., Mill St. Two drilled wells, 300 and 464 feet deep, pumped together, 75,000 gal. per 24 hrs. Is used in boilers along with city water and "tri-soda" (phosphate?). Not much scale reported.	Pts. per mill.	528	224	255	None
		Grs. per gal.	30.8	13.1	14.9	

³¹Normal carbonate = 60 pts. per mill. or 3.5 grs. per gal.
Hydroxide = 12 pts. per mill. or 0.70 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
15	15	25	0.1	....	8.0	7.0	56	....	None	414
0.76	0.88	1.5	0.01	....	0.47	0.41	3.3	....	
21	74	4.0	1.7	293	8.0	0.25	53	28	8.0	415
1.2	4.3	0.23	0.10	17.1	0.47	0.02	3.1	1.6	0.47	
8.5	32	98	1.1	317	16	1.3	54	26	12	416
0.50	1.0	5.7	0.06	18.5	0.93	0.05	3.2	1.5	0.70	
4.9	16	325	0.9	311	352	None	7.0	10	6.0	417
0.29	0.93	18.9	0.05	18.2	20.5		0.41	0.58	0.35	
29	132	23	0.6	301	28	None	192	22	46	418
1.7	7.6	1.3	0.04	17.6	1.6		11.1	1.3	2.7	
17	62	107	0.7	311	110	0.7	42	18	13	419
0.99	3.6	6.3	0.04	18.2	6.4	0.04	2.5	1.1	0.76	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
SALEM—Concluded						
420	Salem Light & Power Co., Depot St. An old coal shaft 60 feet deep. Used for cooling gas engines.	Pts. per mill.	872	624	285	339
		Grs. per gal.	50.9	36.4	16.6	19.8
SANDUSKY						
Samples collected August 19-20, 1915.						
421	City water. The water from Sandusky Bay purified by rapid sand filtration, occasionally with added treatment with hypochlorite of lime. 4,500,000 gal. pumped daily. Used in boilers gives considerable hard scale. Red Star compound seemed to loosen this. The raw Sandusky Bay water did not give a hard scale when it was used.	Pts. per mill.	318	190	95	95
		Grs. per gal.	18.5	11.1	5.4	5.4
422	City water. Untreated water from Sandusky Bay.	Pts. per mill.	346	191	110	81
		Grs. per gal.	20.2	11.1	6.4	4.7
423	Lake Erie water outside of bay. Apparently an abnormal sample, since carbonate hardness is so high.	Pts. per mill.	....	241	240	1.0
		Grs. per gal.	....	14.1	14.0	0.06
SOUTH SOLON						
Sample taken in October, 1915.						
424	J. W. Rapp, 4 miles east of town. Well, 126 feet, 62 feet to rock. Water level 4 feet from surface. The deep wells of this neighborhood are said not to be so hard as the shallow ones.	Pts. per mill.	624	600	400	200
		Grs. per gal.	36.4	35.0	23.3	11.6
SPRINGFIELD						
Samples collected February, 1915.						
425	City water. The city supply is obtained by damming the underground flow of a big gravel deposit and pumping from shallow wells sunk in this gravel. In boilers scale is formed. Most firms using it employ boiler compounds.	Pts. per mill.	404	317	237	80
		Grs. per gal.	23.5	18.4	13.8	4.7

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
42	180	13	3.4	348	16	None	264	22	27	420
2.5	10.5	0.76	0.20	20.3	0.93		15.4	1.3	1.6	
13	54	14	0.2	116	16	0.4	122	20	9.0	421
0.76	3.2	0.81	0.01	6.6	0.93	0.02	7.1	1.2	0.53	
13	54	24	1.4	134	16	0.7	103	6.0	3.0	422
0.76	3.2	1.4	0.08	7.8	0.93	0.04	6.0	0.35	0.18	
17	68	.....	.....	293	.....	.....	.....	.....	47	423
0.99	4.0	.....	.....	17.1	.....	.....	.....	.....	2.7	
86	28	None	0.6	488	8.0	None	125	12	45	424
5.0	5.7		0.04	28.4	0.47		7.3	0.70	2.6	
29	79	5.5	0.36	289	6.0	5.6	74	20	6.0	425
1.7	4.6	0.32	0.02	16.8	0.35	0.33	4.3	1.2	0.35	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or tem- porary hardness, CaCO ₃	Non- carbonate or per- manent hardness, CaCO ₃
SPRINGFIELD—Continued						
426	Metallic Casket Co., corner Columbia and Fisher Sts. Three drilled wells, 141, 126, and 110 feet. Did not give sufficient water though other wells in vicinity gave a good supply.	Pts. per mill.	792	475	355	120
		Grs. per gal.	46.1	27.7	20.7	7.0
427	Fairbanks Building, 7 West Main St. Well 128 feet, 6-in. casing. Water level 50 feet from surface. Pumps an average of 47,000 gal. daily.	Pts. per mill.	578	462	385	77
		Grs. per gal.	33.7	26.9	22.5	4.5
428	Bushnell Building, 18 East Main St. Well 72 feet. Water level 32 feet from surface, 6-in. casing to rock at about 18 feet. Pumps about 15,000 gal. daily. Used in return tubular Brownell boilers. Boilers cleaned every two weeks. Forms hard scale requiring hammer to loosen; also tends to pit boilers. Boiler compound, Buckeye water softener, about 3 qts. daily, used along with open type heater.	Pts. per mill.	728	495	357	138
		Grs. per gal.	42.4	28.9	20.8	8.0
429	Springfield Brewing Co., corner Columbia and Spring Sts. Two drilled wells, 98 and 90 feet, 4½-in. casings, to rock struck at 8 feet. Wells end in gravel. Water level 14 feet from surface. Pumps 20,000 gal. daily. Used in boilers and for general purposes. Forms much hard scale in fire tube boilers, 250 H. P. plant. Hawkeye boiler compound, 1½ lbs. daily used. Feed water preheated with exhaust steam.	Pts. per mill.	814	552	400	152
		Grs. per gal.	47.5	32.2	23.3	8.9
430	Ansted & Burk Co., Warder and Lime-stone Sts. Water of the mill run. At time sample was taken flood stage was just passed. Used in water tube boilers along with soda ash. Boilers cleaned every 6 months, blown off once or twice daily.	Pts. per mill.	402	327	262 ³²	65
		Grs. per gal.	23.4	19.1	15.3	3.8

³²Normal carbonate = 20 pts. per mill. or 1.2 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
47	112	67	9.0	433	36	26	94	66	23	426
2.7	6.5	3.9	0.53	25.3	2.1	1.5	5.5	3.9	1.3	
46	109	32	0.8	470	38	3.9	83	22	31	427
2.7	6.3	1.9	0.05	27.5	2.2	0.23	4.8	1.3	1.8	
62	96	20	0.7	435	70	19.3	103	22	33	428
3.6	5.6	1.2	0.04	25.4	4.1	1.1	6.0	1.3	1.9	
64	115	61	1.4	488	62	26	110	20	47	429
3.7	6.7	3.6	0.08	28.4	3.6	1.5	6.4	1.2	2.7	
33	77	5.2	0.9	320	6.0	6.7	69	34	None	430
1.9	4.5	0.30	0.05	18.7	0.35	0.39	4.0	2.0		

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
SPRINGFIELD—Continued					
431	Springfield Pure Milk Co., 125 Fountain Ave. Drilled well, 132 feet, 6-in. casing. Rock at surface, cased for 60 feet. Blue clay at bottom of well. Level of water 57 feet from surface. Pumps 50 gal. per min.; supply always sufficient. Used for boilers and scrubbing. Brownell type fire tube boilers and Hoppes heater. Hawkeye boiler compound, 2 lbs. per 24 hrs. used.				
	Pts. per mill.	676	525	440	85
	Grs. per gal.	39.4	30.6	25.7	5.0
432	James Leffel & Co., Lagonda Ave. and Big Four R. R. Drilled well, 300 feet, 8-in. casing. Pumps 100 gal. per min. Supply always sufficient. Used for cooling, flushing, hydrostatic boiler testing, and for general purposes around plant. Tried in boilers but was unsatisfactory.				
	Pts. per mill.	790	562	325	237
	Grs. per gal.	46.1	32.8	19.0	13.8
433	K. of P. House. Drilled well, 220 feet, 8-in. casing to bottom. Hard pan at surface for 20 feet, rock rest of way. Water flows out top. Pumped 125 gal. per min. for 10 hrs. on test. Regularly pumps 40,000 gal. per 24 hrs. Used in boilers and laundry after softening. Softening plant consumes 190 lbs. lime and 20 lbs. soda ash per week. Softened water gives no trouble in boilers and is said to cut laundry soap bill in half. Boilers washed down once a month. Feed water is preheated and return water used.				
	Pts. per mill.	394	357	350	7.0
	Grs. per gal.	23.0	20.8	20.4	0.41
434	Big Four R. R. Shops. Fifteen driven wells, close together, 200 feet. Usually pump 6 wells. If all are pumped at once wells go dry. Pumpage is about 379,000 gal. per 24 hrs. Water is softened with lime and soda ash at an average cost during 1914 of 3.97 cents per 1,000 gal. This includes chemicals, labor, repairs, pumping, and depreciation.				
	Pts. per mill.	796	490	350	140
	Grs. per gal.	46.4	28.6	20.4	8.2

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No
65	106	38	0.36	537	28	12.3	81	16	37	431
3.7	6.2	2.2	0.02	31.4	1.6	0.72	4.7	0.93	2.2	
53	137	34	1.0	396	30	7.9	206	30	21	432
3.1	8.0	2.0	0.06	23.2	1.8	0.46	12.0	1.8	1.2	
37	81	13	2.3	427	6.0	0.53	14	22	19	433
2.2	4.7	0.76	0.13	24.9	0.35	0.03	0.82	1.3	1.1	
50	114	83	0.4	427	78	4.2	140	12	10	434
2.9	6.6	4.8	0.02	24.9	4.6	0.25	8.2	0.70	0.58	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
SPRINGFIELD—Continued						
435	Big Four R. R. Shops. This sample was taken from one of the wells pumped separately.	Pts. per mill.	708	527	357	170
		Grs. per gal.	41.3	30.7	20.8	9.9
436	Mast, Foos & Co., Columbia and Isabell Sts. Drilled well, 4½-in. casing. Rain water along with the waste from drinking fountains supplied from this well is used in its boilers by the company. Wrought iron boiler tubes are employed and no boiler trouble due to rain water is reported.	Pts. per mill.	348	277	217	60
		Grs. per gal.	20.3	16.2	12.7	3.5
437	Home Dairy & Standard Ice Cream Co., 323 S. Center St. Three drilled wells, 52, 58 and 61 feet, 6- and 8¼-in. casings. Sample taken from 52-foot well. Water along with soda ash is used in boilers which are cleaned every three weeks.	Pts. per mill.	620	447	355	92
		Grs. per gal.	36.2	26.1	20.7	5.4
438	Same location as No. 437. Sample from 58-foot well.	Pts. per mill.	564	420	337	83
		Grs. per gal.	32.9	24.5	19.7	4.8
439	Nolte Brass Co., 27 W. Jefferson St. Drilled well, 65 feet, 2½-in. casing, to bottom. Rock at 10 feet. Level of water 8 feet from surface. Used for cooling, drinking, and in general about shop.	Pts. per mill.	458	382	332	52
		Grs. per gal.	26.7	22.3	19.4	3.0
440	Robbins & Myers Co., Lagonda Ave. and Leah St. Drilled well, 140 feet. First 28 feet through clay and gravel; blue clay after going through rock at 140 feet. No water at this point. Hole was then filled to top of rock at which point an insufficient supply was obtained.	Pts. per mill.	1152	625	322	303
		Grs. per gal.	67.0	36.5	18.8	17.7
441	O. L. Krieder, R. F. D. No. 1. Drilled well, 85 feet. Water precipitates iron on standing.	Pts. per mill.	650	382	365	17
		Grs. per gal.	37.9	22.3	21.3	0.99

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
51	127	20	0.5	435	20	12.3	125	10	27	435
3.0	7.4	1.2	0.03	25.4	1.2	0.72	7.3	0.58	1.6	
30	61	9.7	0.5	265	8.0	8.5	53	4.0	5.0	436
1.8	3.6	0.57	0.03	15.5	0.47	0.50	3.1	0.23	0.29	
45	105	39	0.24	433	40	24.6	68	14	28	437
2.6	6.1	2.3	0.01	25.3	2.3	1.4	4.0	0.82	1.6	
41	100	28	0.44	411	26	20.5	65	14	16	438
2.4	5.8	1.6	0.03	24.0	1.5	1.2	3.8	0.82	0.93	
37	91	14.6	0.4	405	10	6.5	52	18	19	439
2.2	5.3	0.85	0.02	23.7	0.58	0.38	3.0	1.1	1.1	
51	166	110	8.2	393	42	17.6	205	78	22	440
3.0	9.7	6.4	0.48	22.9	2.5	1.0	12.0	4.6	1.3	
39	89	85	32	445	8.0	None	18	54	11	441
2.3	5.2	5.0	1.9	26.0	0.47		1.1	3.2	0.64	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
SPRINGFIELD—Concluded						
442	Bauer Bros. Co., Sheridan Ave. and Burt St. Driven well, 37 feet, in gravel.	Pts. per mill.	404	370	332	38
		Grs. per gal.	23.5	21.6	19.4	2.2
443	Lagonda Manufacturing Co., 1809 Sheridan Ave. Driven well, 14 feet, in gravel and sand. Used for cooling gas engine, also in steam boilers along with city water.	Pts. per mill.	458	395	332	63
		Grs. per gal.	26.7	23.1	19.4	3.7
444	Ridgely Trimmer Co., Kenton St. near Oak. Three wells, 70 feet, in gravel. Pumped together, 1,300 gal. per hr. Used in boilers and for general purposes.	Pts. per mill.	456	384	332	52
		Grs. per gal.	26.6	22.4	19.4	3.0
445	Kelly-Springfield Roller Co., Kenton Ave. and Oak St. Drilled well, 22 feet.	Pts. per mill.	516	430	340	90
		Grs. per gal.	30.1	25.1	19.8	5.3
446	American Seeding Machine Co., Monroe St. Dug well, 30 feet in gravel. Used part of time in boilers.	Pts. per mill.	620	505	420	85
		Grs. per gal.	36.2	29.5	24.5	5.0
TIFFIN						
Samples collected July 23, 1915.						
447	City water. Two wells, 230 feet, 8- and 10-in. casings, in limestone struck at about 16 feet. Pump 600,000 gal. daily. Wells are 1 mile south of city. Forms hard scale in boilers.	Pts. per mill.	522	349	270	79
		Grs. per gal.	30.4	20.3	15.8	4.6
448	Sandusky River. Water at flood stage when sample was taken. Used in boilers with soda ash which is reported better than former treatment with compounds. No scale trouble.	Pts. per mill.	360	175	127	48
		Grs. per gal.	21.0	10.2	7.4	2.8
449	Pure Milk & Dairy Co., Ella and Sycamore Sts. Drilled well, 106 feet, 6-in. casing. Pumps 30 gal. per min. Used in boilers with soda ash forms medium scale.	Pts. per mill.	470	338	307	31
		Grs. per gal.	27.4	19.7	17.9	1.8

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
37	86	9.4	0.3	405	6.0	3.5	42	14	18	442
2.2	5.0	0.55	0.02	23.7	0.35	0.20	2.5	0.82	1.1	
37	96	13	0.1	405	8.0	8.5	62	10	28	443
2.2	5.6	0.76	0.01	23.7	0.47	0.50	3.6	0.58	1.6	
36	94	20	0.3	405	8.0	None	66	32	26	444
2.1	5.5	1.2	0.02	23.7	0.47		3.9	1.9	1.5	
42	102	14	0.3	415	8.0	4.5	86	14	24	445
2.5	5.9	0.82	0.02	24.2	0.47	0.26	5.0	0.82	1.4	
46	126	27	1.0	512	20	10	66	12	60	446
2.7	7.4	1.6	0.06	29.9	1.2	0.58	3.9	0.70	3.5	
27	96	36	0.4	329	26	1.3	105	20	21	447
1.6	5.6	2.1	0.02	19.3	1.5	0.08	6.1	1.2	1.2	
13.4	48	29	5.4	155	6.0	16	50	62	9.0	448
0.76	2.8	1.7	0.32	9.0	0.35	0.93	2.9	3.6	0.53	
21	101	33	0.8	374	8.0	None	75	36	22	449
1.2	5.9	1.9	0.04	21.8	0.47		4.4	2.1	1.3	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or tem- porary hardness, CaCO ₃	Non- carbonate or per- manent hardness, CaCO ₃
TIFFIN—Concluded						
450	Webster Manufacturing Co., David St. Drilled well, 286 feet, 10-in. casing, to rock, 8-in. hole in rock. Water level 16 feet from surface. Used in boilers with open heater and compound. Not much scale trouble.	Pts. per mill.	448	340	275	65
		Grs. per gal.	26.1	19.8	16.0	3.8
451	Sterling Grinding Wheel Co., Broad Ave. Two wells, 216 feet, 6-in. casing, and 200 feet, 3-in. casing. Water level 10 feet from surface. Makes much scale in boilers.	Pts. per mill.	622	428	290	138
		Grs. per gal.	36.3	25.0	16.9	8.0
452	Smith Coal & Ice Co., Hudson and Franklin Sts. Three drilled wells, 160 feet, rock struck at 12 feet. Used in boilers after softening with lime and soda ash by the Dodge softener. A little scale even after softening.	Pts. per mill.	504	370	302	68
		Grs. per gal.	29.4	21.6	17.6	4.0
453	National Orphans Home. Drilled well, 302 feet, 6-in. casing, rock at surface. Water level 11 feet from surface. Pumps 900 barrels per day. Used in boilers along with a liquid compound. Forms hard scale, however, that must be hammered off. Water is softened for use in the laundry.	Pts. per mill.	678	452	282	170
		Grs. per gal.	39.5	26.4	16.4	9.9
454	Hubach Brewing Co., Madison St. Drilled well, 224 feet, rock at 10 feet. Water level 26 feet from surface. Used in boilers along with city water forms hard scale.	Pts. per mill.	646	441	330	111
		Grs. per gal.	37.7	25.7	19.2	6.5
455	Mercy Hospital, West Market St. Drilled well, 180 feet, in rock. Used for drinking.	Pts. per mill.	386	305	290	15
		Grs. per gal.	22.5	17.8	16.9	0.88

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potas- sium), Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
30	86	26	0.56	335	6.0	0.4	107	18	15	450
1.8	5.0	1.5	0.03	19.5	0.35	0.02	6.2	1.1	0.88	
42	101	34	0.3	354	12	1.7	161	18	29	451
2.5	5.9	2.0	0.02	20.6	0.70	0.10	9.4	1.1	1.7	
34	92	32	2.0	368	10	0.6	110	46	27	452
2.0	5.4	1.9	0.11	21.5	0.58	0.04	6.4	2.7	1.6	
42	111	42	0.7	344	16	0.5	180	6.0	23	453
2.5	6.5	2.5	0.04	20.0	0.93	0.03	10.5	0.35	1.3	
37	114	46	0.4	403	26	None	141	26	29	454
2.2	6.6	2.7	0.02	23.4	1.5		8.2	1.5	1.7	
30	72	31	0.5	354	6.0	0.8	58	18	15	455
1.8	4.2	1.9	0.03	20.6	0.35	0.05	3.4	1.1	0.88	

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃	
TOLEDO						
Samples taken August 16 to 18, 1915.						
456	City water. Maumee River. Water is purified by rapid sand filtration and sterilizing with chloride of lime. Alum is used as coagulant. Pumped 20,500,000 gal. per day. Used in boilers by a number of firms. Forms some hard scale.	Pts. per mill.	774	389	100	289
		Grs. per gal.	45.1	22.7	5.8	16.9
457	Valentine Building, Adams and St. Clair Sts. Well, 618 feet, 8-in. and 5½-in. casings. Rock struck at about 90 feet. Pumps 45,000 gal. daily. Used for general purposes in building. City water is employed in the boilers.	Pts. per mill.	754	382	102	280
		Grs. per gal.	44.0	22.3	5.9	16.3
458	Willys-Overland Co., W. Central Ave. Five drilled wells, 530 feet, 10-in. casings, 90 feet to rock. Water level 50 to 80 feet from surface. Pumpage 3,000 gal. from each well. Used for drinking.	Pts. per mill.	2128	1216	172	1044
		Grs. per gal.	124.0	70.9	10.0	61.0
459	Same location as No. 458. Ottawa River. Used in boilers with open heater. Some soft scale is formed, reported not nearly so bad as the city water which makes a hard scale.	Pts. per mill.	494	321	242	79
		Grs. per gal.	28.8	18.7	14.1	4.6
460	National Supply Co., Bishop and Princeton Sts. Drilled well, 375 feet, 8-in. casing. Water level 100 feet from surface. Water contains hydrogen sulfide. Used for drinking. An ordinary steel pipe is eaten through in about 6 months. Galvanized pipes are attacked at the joints only.	Pts. per mill.	2018	1122	125	997
		Grs. per gal.	118.0	65.4	7.3	58.2
461	Citizens Ice Co., Council St. Drilled well, 500 feet, rock at about 300 feet. Pumps 300 gal. per min. Water level 80 feet from surface. Used for cooling. City water employed in boilers.	Pts. per mill.	1926	1048	115	933
		Grs. per gal.	112.0	61.1	6.7	54.4

GROUND WATERS OF OHIO—Continued

Magnesium, Mg.	Calcium, Ca.	Sodium (Potassium), Na.	Iron, Fe.	Bicarbonate ion, HCO ₃	Chloride ion, Cl.	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
37	94	47	0.4	122	56	0.9	246	36	3.0	456
2.2	5.5	2.7	0.02	7.1	3.3	0.05	14.4	2.1	0.18	
36	93	49	0.4	124	54	0.8	258	34	3.0	457
2.1	5.4	2.9	0.02	7.2	3.2	0.05	15.0	2.0	0.18	
115	296	76	0.36	210	22	0.6	732	124	10	458
6.7	17.3	4.4	0.02	12.2	1.3	0.04	42.7	7.2	0.58	
22	92	18	5.8	295	8.0	7.5	98	38	10	459
1.3	5.4	1.1	0.34	17.2	0.47	0.44	5.7	2.2	0.58	
109	269	69	0.36	152	50	None	804	66	10	460
6.3	15.7	4.0	0.02	8.9	2.9		46.9	3.9	0.58	
105	247	58	0.6	140	56	None	660	46	7.0	461
6.1	14.3	3.4	0.04	8.2	3.3		38.5	2.7	0.41	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or tem- porary hardness, CaCO ₃	Non- carbonate or per- manent hardness, CaCO ₃
TOLEDO—Continued						
462	Owens Bottle Machine Co., Detroit Ave. and M. C. R. R. Drilled well, 356 feet, 3-in. casing. Water contains hydrogen sulfide. Used for drinking and cooling.	Pts. per mill.	3536	1935	155	1780
		Grs. per gal.	206.0	113.0	9.0	103.0
463	Buckeye Brewing Co., Bush St. Drilled well, 650 feet, 6-in. casing. (Another well 150 feet from this one and 625 feet deep went dry.) Used for cooling.	Pts. per mill.	804	411	105	306
		Grs. per gal.	46.9	24.0	6.1	17.9
464	Huebner-Toledo Breweries, Hamilton St. Two drilled wells, 500 feet, 8-in. casings, rock at 100 feet. Water level 100 feet from surface. If pumped too heavily this well runs dry. Used in condensers. City water employed in boilers.	Pts. per mill.	760	395	117	278
		Grs. per gal.	44.3	23.1	6.8	16.2
465	Toledo Ice & Storage Co., Nebraska Ave. Two drilled wells, 400 feet, 8-in. casings. Water level 175 to 200 feet from surface. Pump 85 gal. per min. for 24 hrs. Used for condensing. City water employed in boilers along with graphite to prevent scale from sticking.	Pts. per mill.	930	452	107	345
		Grs. per gal.	54.3	26.4	6.2	20.1
466	Toledo Grain & Milling Co., Harrison and Mill Sts. Drilled well, 308 feet, 6-in. casing. Used for drinking.	Pts. per mill.	542	285	125	160
		Grs. per gal.	31.6	16.6	7.3	9.3
467	Same location as No. 466. Canal fed by Maumee River. Heavy rains at time sample was taken. Used in boilers where it forms some scale but softer than the scale caused by the city water.	Pts. per mill.	454	188	162	26
		Grs. per gal.	26.5	11.0	9.4	1.5
468	Toledo State Hospital, Detroit and Arlington Sts. Three wells, 78 to 90 feet, 6- to 10-in. casings. Used for drinking. City water is employed in the boilers. Formerly there was much trouble from hard scale sticking to the tubes but the engineer reports that since using graphite the scale remains loose.	Pts. per mill.	576	280	145	135
		Grs. per gal.	33.6	16.3	8.5	7.9

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potas- sium), Na	Iron, Fe	Bicar- bonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
179	480	101	1.4	189	48	None	1144	None	16	462
10.4	28.0	5.9	0.08	11.0	2.8		66.7		0.93	
40	98	55	0.8	128	50	0.6	270	10	3.0	463
2.3	5.7	3.2	0.05	7.4	2.9	0.04	15.8	0.58	0.18	
39	94	60	0.3	143	48	0.3	228	None	4.0	464
2.3	5.5	3.5	0.02	8.3	2.8	0.02	13.3		0.23	
44	109	67	0.36	130	64	None	264	28	3.0	465
2.6	6.3	3.9	0.02	7.6	3.7		15.4	1.6	0.18	
27	70	49	0.3	152	22	0.9	196	34	3.0	466
1.6	4.1	2.9	0.02	8.9	1.3	0.05	11.4	2.0	0.18	
16	49	52	9.0	198	10	5.0	48	126	7.0	467
0.93	2.9	3.0	0.53	11.5	0.58	0.29	2.8	7.4	0.41	
27	68	70	0.3	177	26	0.4	211	18	9.0	468
1.6	4.0	4.1	0.02	10.4	1.5	0.02	12.3	1.1	0.53	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
TOLEDO—Concluded						
469	Lucas County Infirmary, Arlington Ave. Drilled well.	Pts. per mill.	468	207	140	67
		Grs. per gal.	27.3	12.1	8.2	3.9
470	Toledo Ship Building Co., Front St. Drilled well, 529 feet, 6-in. casing. Water level 90 feet from surface. Used for drinking. River water softened by lime and soda ash is used in the boilers.	Pts. per mill.	1682	911	92	819
		Grs. per gal.	98.1	53.1	5.4	47.8
471	Toledo Furnace Co., Front St. Drilled well, 525 feet, 8-in. casing, rock at 110 feet. Water level 58 feet from surface. Used for drinking.	Pts. per mill.	2344	1301	95	1206
		Grs. per gal.	137.0	75.9	5.5	70.4
472	Same location as No. 471. Maumee River. For boilers this water is softened by lime and soda ash by the We-fu-go system. The cost of the softening including labor and maintenance is 3 cents per 1,000 gal.	Pts. per mill.	320	182	147	35
		Grs. per gal.	18.7	10.6	8.5	2.0
473	Same location as No. 471. Maumee River water after softening with lime and soda ash by We-fu-go system. In the boilers this softened water makes very little scale, $\frac{1}{64}$ in. being reported for 3 months running. In 3 months 45 lbs. of scale per boiler was removed. Before softening, a 60-day run had produced 650 lbs.	Pts. per mill.	222	33	(³³)	33
		Grs. per gal.	13.0	1.9	....	1.9
474	Mrs. James H. Biddle. Farm on Maumee River near Toledo. Well 260 feet. Flows 20,000 gal. per day.	Pts. per mill.	3832	2065	137	1928
		Grs. per gal.	223.0	120.0	8.0	113.0

TROY

Sample taken in March, 1916.

City water. No analyses were made of the city water. Reports show that it is obtained from wells and is hard.
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³³Normal carbonate = 40 pts. per mill. or 2.3 grs. per gal.
Hydroxide = 30 pts. per mill. or 1.8 grs. per gal.

GROUND WATERS OF OHIO—Continued

[illegible]

TABLE XX

No	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
TROY—Concluded						
475	Hobart Manufacturing Co. Driven well 50 feet. Contains hydrogen sulfide. Used in boiler with Buckeye Chemical Co. compound.	Pts. per mill.	402	356	280	76
		Grs. per gal.	23.4	20.8	16.3	4.4
UHRICHSVILLE						
Samples taken November 11, 1915.						
476	Buckeye Sewer Pipe Co. Drilled well, 100 feet, 6-in. casing, ends in rock. Used in boilers with Lord's compound. Soft scale only forms.	Pts. per mill.	442	315	222	93
		Grs. per gal.	25.8	18.4	12.9	5.4
477	Indian Hill Coal Co. Drilled well, 95 feet, 6-in. casing. Used in boilers with Perolene compound. Soft scale only.	Pts. per mill.	396	286	245	41
		Grs. per gal.	23.1	16.7	14.3	2.4
URBANA						
478	Urbana Packing Co. Well 33 feet in gravel. Very large supply of water. Forms hard scale in boilers. Is also used for cooling ammonia condenser and found entirely satisfactory.	Pts. per mill.	436	360	280	80
		Grs. per gal.	25.4	21.0	16.3	4.7
VERMILION						
Sample collected September, 1915.						
479	Vermilion Oil & Gas Co. Drilled well, 550 feet. This well was apparently sunk for oil or gas and was continued to a depth of over 2,000 feet. The sample of water was, however, from the 550-foot level. It contains hydrogen sulfide and should be looked upon as a brine rather than as a water.	Pts. per mill.	41108	13770	475	13295
		Grs. per gal.	2397.0	803.0	27.7	775.0
WARREN						
Samples collected October 3-4, 1915.						
480	City water. Mahoning River, purified by rapid sand filtration, using alum and lime as coagulant. ... 1,500,000 gal. pumped daily. The raw river water is used in boilers. Gives a little hard scale. Report that the filtered water gave a harder scale.	Pts. per mill.	282	187	102	85
		Grs. per gal.	16.4	10.9	5.9	5.0

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
34	86	7.1	0.4	342	20	None	67	....	15	475
2.0	5.0	0.41	0.02	19.9	1.2		3.9	....	0.88	
26	84	42	2.6	271	8.0	2.8	105	12	21	476
1.5	4.9	2.5	0.15	15.7	0.47	0.16	6.1	0.70	1.2	
19.5	82	42	0.6	299	8.0	1.0	82	10	21	477
1.1	4.8	2.5	0.04	17.4	0.47	0.06	4.8	0.58	1.2	
34	88	33	0.1	342	18	20	53	....	20	478
2.0	5.1	1.9	0.01	19.9	1.1	1.2	3.1	....	1.2	
207	5168	4006	4.6	579	2500	None	1200	....	Acid	479
12.1	301.0	234.0	0.27	33.8	146.0		70.0	....	
17	47	9.0	0.4	124	16	1.2	86	34	8.0	480
0.99	2.7	0.53	0.02	7.2	0.93	0.07	5.0	2.0	0.47	

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
WARREN—Concluded					
481	Western Reserve Furniture Co., N. Tod Ave. Drilled well, 120 feet, rock at about 20 feet, ends in sandstone. Water level 28 feet from surface. Used in boilers without compound. No scale trouble. Very little sludge. An open feed water heater removes some sludge.	Pts. per mill. 824 Grs. per gal. 48.1	34 2.0	402 ³⁴ 23.4	None
482	Warren Iron & Steel Co., Dana Ave. Two wells, about 160 feet, 6-in. casing, ending in rock. Used in boilers with open feed water heater which removes a large amount of sludge. Some city water is also used in the boilers. Very little scale but after running a week there is trouble from foaming when the water has become concentrated.	Pts. per mill. 568 Grs. per gal. 33.1	267 15.5	382 22.3	None
483	Peoples Ice & Cold Storage Co., Linden Ave. Three drilled wells, 155 feet, 6- and 8-in. casings. Pump 125 gal. per min. Used for cooling and in boilers. Tri sodium phosphate added to boiler water. No scale. A precipitate forms on outside of condensers.	Pts. per mill. 852 Grs. per gal. 49.7	397 23.2	295 17.2	102 5.9
484	Peerless Electric Co., W. Market St. Drilled well, 200 feet, 6-in. casing, shale at 17 feet, pumps 750 gal. per min. Used for drinking.	Pts. per mill. 1228 Grs. per gal. 71.6	36 2.1	382 ³⁵ 22.3	None
485	Trumbull Steel Co., S. Pine St. Drilled well, 106 feet, 4-in. casing, ending in white sandstone. Used for drinking. Water from Mahoning River used in boilers. No scale trouble reported.	Pts. per mill. 1984 Grs. per gal. 116.0	56 3.3	370 ³⁶ 21.6	None

³⁴Normal carbonate = 10 pts. per mill. or 0.58 grs. per gal.³⁵Normal carbonate = 20 pts. per mill. or 1.2 grs. per gal.³⁶Normal carbonate = 60 pts. per mill. or 3.5 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
3.6	7.6	287	0.6	490	98	2.0	90	32	None	481
0.21	0.44	16.7	0.04	28.5	5.7	0.12	5.3	1.9		
23	69	109	0.5	466	54	None	47	36	33	482
1.3	4.0	6.4	0.03	27.2	3.2		2.7	2.1	1.9	
23	121	127	5.4	360	100	None	162	42	43	483
1.3	7.0	7.5	0.32	21.0	5.8		9.4	2.5	2.5	
3.6	8.4	451	0.5	466	380	2.7	79	90	None	484
0.21	0.49	26.3	0.03	27.2	22.2	0.16	4.6	5.3		
6.1	12.4	739	1.0	451	870	None	None	62	None	485
0.36	0.72	43.1	0.06	26.4	50.8			3.6		

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
WASHINGTON C. H.						
Samples taken January 28, 1916.						
486	City water. Six deep wells, 175 feet, 8-in. casings. Six shallow, dug wells, 30 feet. Larger part of supply comes from the shallow wells. Pump 650,000 gal. daily. Used in boilers with Perolene compound gives loose scale.	Pts. per mill. Grs. per gal.	316 18.4	297 17.3	237 13.8	60 3.5
487	Washington Manufacturing Co. Drilled well, 250 feet, 4-in. casing. Used in boilers with Lord compound gives loose scale.	Pts. per mill. Grs. per gal.	492 28.7	413 24.1	355 20.7	58 3.4
488	Washington Milling Co. Drilled well, 165 feet, 8-in. casing, ends in rock. Used in boilers with graphite. Loosescale only.	Pts. per mill. Grs. per gal.	480 28.0	408 23.8	362 21.1	46 2.7
489	Washington Gas & Electric Co. Drilled well, 98 feet. Used in boilers with graphite which keeps scale loose.	Pts. per mill. Grs. per gal.	486 28.4	404 23.6	370 21.6	34 2.0
490	Fayette County Creamery. Drilled well, 150 feet, 6-in. casing. Used in boilers with graphite to keep scale loose.	Pts. per mill. Grs. per gal.	538 31.4	446 26.0	337 19.7	109 6.4
491	Washington Ice Co. Three dug wells, 18 to 60 feet. Water supply short in dry seasons. Used in boilers after softening with lime and soda ash, by Eureka system.	Pts. per mill. Grs. per gal.	526 30.7	392 22.9	292 17.0	100 5.8
WAUSEON						
Sample taken in spring of 1916.						
492	Van Camp Packing Co. Well 190 feet. Pumps about 1,500 gal. per hr. Used in boiler causes some scale and a little foaming.	Pts. per mill. Grs. per gal.	602 35.1	119 6.9	347 20.2	None

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
30	69	None	0.1	289	8.0	7.5	38	....	25	486
1.8	4.0		0.01	16.8	0.47	0.44	2.2	....	1.5	
42	95	26	0.4	433	8.0	None	78	....	57	487
2.5	5.5	1.5	0.02	25.3	0.47		4.6	....	3.3	
46	87	21	2.2	442	8.0	None	62	....	44	488
2.7	5.1	1.2	0.13	25.7	0.47		3.6	....	2.6	
46	86	26	1.3	451	10	None	52	....	40	489
2.7	5.0	1.5	0.08	26.4	0.58		3.0	....	2.3	
56	86	21	0.4	411	14	0.9	115	....	45	490
3.3	5.0	1.2	0.02	24.0	0.82	0.05	6.7	....	2.6	
41	89	32	0.9	356	42	17	78	....	34	491
2.4	5.2	1.9	0.05	20.7	2.5	0.99	4.6	....	2.0	
11	30	192	0.4	423	84	None	24	....	Acid	492
0.64	1.8	11.2	0.02	24.6	4.9		1.4	....	

TABLE XX

No.	Description	Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃	
WAYNESBURG						
Sample taken December, 1915.						
493	Whitacre Fireproofing Co. Water from cistern at side of Big Sandy Creek. Creek water is supposed to filter through sand and gravel into this cistern. Used in boilers the following was reported: "The principal trouble seems to be foaming of the water and when it foams and comes through the steam line to the engine there seems to be a fine dust without any grit whatever, and dries the oil up so that it is almost impossible to get sufficient oil pumped to keep the valves working."	Pts. per mill.	194	157	105	52
		Grs. per gal.	11.2	9.1	6.1	3.0
WELLSTON						
Sample taken January 26, 1916.						
494	City water. Well, 30 feet, 24 feet in diameter, walled with stone, in sand, 30 feet from creek. Pumps 500,000 gal. per 24 hrs. Used in boilers with soda ash. Reported that in the fall when the creek is full of leaves the water causes foaming in the boilers.	Pts. per mill.	94	48	17	51
		Grs. per gal.	5.5	2.8	0.99	1.8
WOODSTOCK						
Samples taken March, 1916.						
495	Zymo Magnetic Water Co., Fountain Park, near Woodstock. A number of flowing wells located in a small grove. The deepest is said to be 1,800 feet. The water is sold for medicinal purposes and as a table water.	Pts. per mill.	478	388	355	33
		Grs. per gal.	27.9	22.6	20.7	1.9
496	Same location as No. 495.	Pts. per mill.	450	400	385	15
		Grs. per gal.	26.3	23.3	22.5	0.88
497	Same location as No. 495.	Pts. per mill.	488	387	360	27
		Grs. per gal.	28.5	22.5	21.0	1.6

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
11	45	None	0.24	128	8.0	1.0	51	6.0	Acid to ph'th'n	493
0.64	2.6		0.01	7.4	0.47	0.06	3.0	0.35		
4.9	11.2	9.0	0.8	21	8.0	1.0	38	....	6.0	494
0.29	0.65	0.53	0.05	1.21	0.47	0.06	2.2	....	0.35	
39	91	20	4.0	433	Trace	0.25	56	14	Acid to ph'th'n	495
2.3	5.3	1.2	0.23	25.3		0.02	3.3	0.82		
41	92	12	2.2	470	Trace	None	24	16	Acid to ph'th'n	496
2.4	5.4	0.70	0.13	27.5			1.4	0.93		
37	93	22	1.4	439	6.0	None	56	....	50	497
2.2	5.4	1.3	0.08	25.6	0.35		3.3	....	2.9	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
WOOSTER						
Sample taken March, 1916.						
498	Wooster Brush Co. Well, 105 feet, 4-in. casing, in gravel. Used in boilers with compound, and for boiling bristles.	Pts. per mill. Grs. per gal.	550 32.1	393 22.9	207 12.1	186 10.8
XENIA						
Samples taken January 29, 1916.						
499	City water. Eighteen drilled wells, 40 feet, 6-, 8- and 10-in. casings, in sand. Pump 600,000 gal. daily. In summer the supply runs low. Used in boilers with Magic compound. Much hard scale and some trouble with pitting. An open heater removes much sludge.	Pts. per mill. Grs. per gal.	774 45.1	596 34.8	345 20.1	251 14.7
500	Hoover & Allison Co. Four driven wells, 35 feet, 6-in. casings, in sand and gravel. Water supplies three mills. At one a Hoppes live steam purifier removes most of scale. Other mills not employing purifiers have trouble with scale.	Pts. per mill. Grs. per gal.	708 41.3	548 32.0	345 20.1	203 11.8
501	Shawnee Refrigeration Co., Mill St. Four dug wells, 25 feet, 20 feet in diameter. Capacity 300,000 gal. per day. Used for condensing and in boilers. Softened with lime and soda ash. No trouble from scale since softening. Quantity of water varies with the seasons. Company reports putting down a well 800 feet deep but got no water.	Pts. per mill. Grs. per gal.	772 45.0	531 31.0	362 21.1	169 9.9
502	Western Creamery Co. Drilled well, 64 feet, 4-in. casing. Pumps 30-gal. per min. for 12 hrs. Water contains hydrogen sulfide. Used in boilers with graphite. There is a good deal of soft scale easily removed. Trouble from pitting at water level is such that all tubes are removed every year.	Pts. per mill. Grs. per gal.	556 32.4	523 30.5	452 26.4	71 4.1

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
28	111	12	0.3	252	48	None	117	....	Acid	498
1.6	6.5	0.70	0.02	14.8	2.8		6.8	....	
53	150	20	0.4	421	22	1.4	231	....	60	499
3.1	8.8	1.2	0.02	24.5	1.3	0.08	13.5	....	3.5	
51	135	21	0.16	421	28	4.5	173	....	50	500
3.0	7.9	1.2	0.01	24.5	1.6	0.26	10.1	....	2.9	
50	130	43	0.4	442	44	40	128	....	60	501
2.9	7.6	2.5	0.02	25.7	2.6	2.3	7.5	....	3.5	
52	123	7.0	4.0	551	18	None	43	....	75	502
3.0	7.2	0.41	0.23	32.2	1.1		2.5	....	4.4	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
XENIA—Concluded						
503	Ohio Soldiers' & Sailors' Orphans Home. Two wells. Water level 24 feet from surface. Pump 80,000 gal. per day from each well. Used for drinking. Creek water softened by Northern system is used by the Home in its boilers. Trouble from pitting is reported. See No. 504.					
		Pts. per mill.	460	426	350	76
		Grs. per gal.	26.8	24.9	20.4	4.4
504	Same location as No. 503. Softened creek water.					
		Pts. per mill.	216	145	57 ³⁷	88
		Grs. per gal.	12.6	8.5	3.3	5.1
YELLOW SPRINGS						
Samples taken February, 1916.						
505	Magnetic Spring, Neff Park. This water is supposed to have curative properties.					
		Pts. per mill.	370	343	300	43
		Grs. per gal.	21.6	20.0	17.5	2.5
506	Whitman St. town pump. About 80 feet in depth.					
		Pts. per mill.	602	501	402	99
		Grs. per gal.	35.1	29.3	23.4	5.8
507	Antioch College well. About 80 feet in depth.					
		Pts. per mill.	494	424	340	84
		Grs. per gal.	28.8	24.7	19.8	4.9
508	The famous Yellow Spring. This spring got its name from the huge deposits of yellow material consisting of calcium carbonate colored with partially oxidized iron oxide. The flow of water is about 110 gal. per min.					
		Pts. per mill.	404	402	375	27
		Grs. per gal.	23.6	23.4	21.9	1.6
YORKVILLE						
509	Yorkville well.					
		Pts. per mill.	1468	869	247	622
		Grs. per gal.	85.7	50.7	14.4	36.3
510	Private well near Yorkville.					
		Pts. per mill.	1396	804	227	577
		Grs. per gal.	81.4	46.9	13.2	33.7
YOUNGSTOWN						
Samples taken June 1-4, 1915.						
511	City water. Raw Mahoning River water. The Carnegie and Brier Hill steel mills are above the point of sampling.					
		Pts. per mill.	364	185	80	105
		Grs. per gal.	21.2	10.8	4.7	6.1

³⁷Normal carbonate = 75 pts. per mill. or 4.4 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
41	102	5.0	0.2	427	12	5.5	45	....	50	503
2.4	5.9	0.29	0.01	24.9	0.70	0.32	2.6	....	2.9	
21	24	24	0.6	69	6.0	10	26	....	None	504
1.2	1.4	1.4	0.04	4.0	0.35	0.58	1.5	....	
35	79	None	0.1	366	6.0	20	15	....	15	505
2.0	4.6		0.01	21.4	0.35	1.2	0.88	....	0.88	
52	114	18	2.4	490	20	21	61	....	53	506
3.0	6.6	1.1	0.14	28.5	1.2	1.2	3.6	....	3.1	
44	98	8.0	0.5	415	14	20	56	....	18	507
2.6	5.7	0.47	0.03	24.2	0.82	1.2	3.3	....	1.1	
41	93	None	1.0	457	6.0	0.5	20	....	30	508
2.4	5.4		0.06	26.7	0.35	0.03	1.2	....	1.8	
59	250	86	0.5	301	40	10	663	....	28	509
3.4	14.6	5.0	0.03	17.6	2.3	0.58	38.7	....	1.6	
53	234	86	0.6	277	38	11	600	....	24	510
3.1	13.6	5.0	0.04	16.1	2.2	0.64	35	....	1.4	
16	48	24	4.4	98	30	4.7	95	14	11	511
0.93	2.8	1.4	0.26	5.7	1.8	0.27	5.5	0.82	0.64	

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
YOUNGSTOWN—Continued						
512	City water. Mahoning River water after filtering.	Pts. per mill. Grs. per gal.	376 21.9	200 11.7	70 4.1	130 7.6
513	City water. Mahoning River water above all city factories. The steel mills of Niles and Warren, however, empty their refuse into the river above this point.	Pts. per mill. Grs. per gal.	344 20.0	167 9.7	75 4.4	92 5.4
514	Block Gas Mantle Co., Logan Ave. Two wells, 210 feet, in blue shale. Used for drinking.	Pts. per mill. Grs. per gal.	1210 71.0	90 5.3	272 ³⁸ 15.8	None
515	Same location as No. 514. Driven well, 90 feet. Used for drinking.	Pts. per mill. Grs. per gal.	502 29.2	102 5.9	217 ³⁸ 12.6	None
516	Same location as No. 514. Water from Crab Creek. Cannot be used in boilers on account of sulfuric acid in stream from plants above.	Pts. per mill. Grs. per gal.	328 19.1	147 8.6	47 2.7	100 5.8
517	General Fireproofing Co., Logan Ave. Crab Creek. Water is practically all from springs and abandoned coal mines. Used in boilers with feed water heater. Tri sodium phosphate and soda ash are put into boilers. Not much hard scale reported.	Pts. per mill. Grs. per gal.	212 12.4	137 8.0	110 6.4	27 1.6
518	Dollar Savings & Trust Bldg., corner Wick Ave. and Public Square. Drilled well, 110 feet. Used for flushing, in wash bowls, and for drinking.	Pts. per mill. Grs. per gal.	1126 66.0	525 30.6	295 17.2	230 13.4
519	Smith Brewing Co., 425 West Federal St. Well, 52.5 feet, 13.5 feet in diameter, in gravel. Pumps 40 gal. per min. Used for cooling. River water is employed in boilers.	Pts. per mill. Grs. per gal.	984 57.3	480 28.0	287 16.7	193 11.2

³⁸Normal carbonate = 5 pts. per mill. or 0.29 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
17 0.99	52 3.0	21 1.2	0.5 0.03	85 5.0	28 1.6	3.8 0.22	114 6.6	10 0.58	11 0.64	512
16 0.93	41 2.4	21 1.2	2.2 0.13	91 5.4	18 1.1	3.8 0.22	93 5.4	18 1.1	9.0 0.53	513
7.3 0.43	24 1.4	616 36.0	2.8 0.16	332 19.3	520 30.3	None	1.4 0.08	5.0 0.29	None	514
9.7 0.57	25 1.5	115 6.7	0.8 0.05	265 15.4	146 8.5	0.5 0.03	6.4 0.37	4.5 0.26	None	515
16 0.95	33 1.9	21 1.2	13.6 0.80	57 3.3	8.0 0.46	1.5 0.09	102 5.9	58 3.4	30 1.7	516
11 0.64	37 2.2	14 0.82	1.0 0.06	134 7.8	6.0 0.35	2.0 0.11	42 2.5	20 1.2	2.0 0.11	517
39 2.3	146 8.6	113 6.6	2.0 0.11	360 21.0	196 11.4	None	145 8.4	44 2.6	18 1.1	518
38 2.2	130 7.6	133 7.7	16 0.93	350 20.4	170 9.9	None	165 9.6	18 1.1	20 1.2	519

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness CaCO ₃
YOUNGSTOWN—Continued						
520	Crystal Ice & Storage Co., West Rayen Ave. and Erie R. R. Four wells, 300 feet, rock at 40 feet. Cannot be pumped at full capacity of the pumps. Used for cooling. Was tried in boilers but gave too much scale.	Pts. per mill.	830	417	300	117
		Grs. per gal.	48.4	24.3	17.5	6.8
521	Crystal Ice & Storage Co. Well in school house yard north of St. Elizabeth Hospital. Source of water supposed to be from an abandoned coal mine. The company proposes to try this water in its boilers.	Pts. per mill.	562	382	240	142
		Grs. per gal.	32.7	22.2	14.0	8.3
522	Renner Brewing Co., Pike St. Two cisterns, walled with brick and boiler plate.	Pts. per mill.	692	372	167	205
		Grs. per gal.	40.3	21.6	9.7	11.9
523	Youngstown Sheet & Tube Co., East Youngstown. No. 6 well, 108 feet. Used for drinking.	Pts. per mill.	220	120	160 ³⁹	None
		Grs. per gal.	12.8	7.0	9.3	
524	Same location as No. 523. No. 9 well, 110 feet. Located 3,000 feet from well No. 6. Used for drinking.	Pts. per mill.	182	130	137	None
		Grs. per gal.	10.6	7.6	8.0	
525	Same location as No. 523. Raw water from Mahoning River. Used in boilers after softening with lime and soda ash by We-fu-go system.	Pts. per mill.	396	182	67	115
		Grs. per gal.	23.1	11.0	3.9	6.7
526	Same location as No. 523. Mahoning River water after softening. This water gives no scale trouble but causes priming when water becomes concentrated in the boilers. It is reported, however, that blowing off does not seem to prevent it.	Pts. per mill.	414	17	None ⁴⁰	17
		Grs. per gal.	24.1	1.0		1.0

³⁹Normal carbonate = 5 pts. per mill. or 0.29 grs. per gal.⁴⁰Normal carbonate = 90 pts. per mill. or 5.3 grs. per gal.

Hydroxide = 20 pts. per mill. or 1.2 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
30	117	120	0.8	366	132	None	168	26	13	520
1.8	6.8	7.0	0.05	21.4	7.6		9.8	1.5	0.76	
39	89	17	0.6	293	26	None	123	30	53	521
2.3	5.2	1.0	0.04	17.1	1.5		7.1	1.8	3.1	
24	109	32	0.3	204	64	22	125	28	6.0	522
1.4	6.3	1.9	0.02	11.8	3.7	1.3	7.3	1.6	0.35	
9.7	32	36	0.4	195	20	0.25	Very little	22	None	523
0.57	1.9	2.1	0.02	11.3	1.2	0.01	1.3			
11	34	11.6	0.5	167	12	None	Very little	30	4.0	524
0.64	2.0	0.68	0.03	9.8	0.70		1.8		0.23	
16	47	31	7.0	82	30	3.0	107	12	26	525
0.93	2.7	1.8	0.41	4.8	1.8	0.18	6.2	0.7	1.5	
4.9	None	128	0.26	None	42	0.5	115	28	None	526
0.29		7.5	0.02		2.5	0.03	6.7	1.6		

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
YOUNGSTOWN—Concluded						
527	General Fireproofing Co., Logan Ave. Drilled well, 145 feet, 5-in. casing, in rock. Pumps 6 gal. per min. for 12 hrs. Used for drinking.	Pts. per mill.	250	177	167	10
		Grs. per gal.	14.6	10.3	9.7	0.58
ZANESVILLE						
Samples taken April 15-16, 1915.						
528	City water. Muskingum River water treated with hypochlorite. Pumpage 8,000,000 gal. daily. The city water is used in boilers by the B. & O., Pennsylvania, Wheeling & Lake Erie, and Ohio River & Western Railroads. At the pumping station graphite was employed as a scale preventive but was not found satisfactory.	Pts. per mill.	454	225	112	113
		Grs. per gal.	26.5	13.1	6.5	6.6
529	Hemmer Ice Cream Co., 335 Sixth St. Driven well, 75 feet, 6-in. casing, in gravel. Water level 30 feet from surface. Pumps 75 gal. per min.	Pts. per mill.	926	592	322	270
		Grs. per gal.	54.0	34.5	18.8	15.8
530	American Encaustic Tiling Co., Linden Ave. Four driven wells, two 30 feet and two 42 feet. Pumped together yield 100,000 gal. per 24 hrs. Used for drinking and manufacturing purposes.	Pts. per mill.	594	417	232	185
		Grs. per gal.	34.6	24.3	13.5	10.8
531	Same location as No. 530. City water from mains before treatment. Used in boilers after softening with lime and soda ash by We-fu-go system. No scale trouble.	Pts. per mill.	476	227	115	112
		Grs. per gal.	27.8	13.2	6.7	6.5
532	Same location as No. 530. City water after softening.	Pts. per mill.	364	32	(41)	32
		Grs. per gal.	21.2	1.9	....	1.9

⁴¹Normal carbonate = 40 pts. per mill. or 2.3 grs. per gal.
Hydroxide = 30 pts. per mill. or 1.8 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate ion, SO ₄	Silica, SiO ₂	Free carbon dioxide, CO ₂	No.
13	49	20	0.7	204	24	0.25	Very little	46	5.0	527
0.76	2.9	1.2	0.41	11.8	1.4	0.02		2.7	0.29	
12.2	70	47	1.4	137	88	1.8	66	None	1.0	528
0.71	4.1	2.7	0.08	7.9	5.1	0.11	3.9		0.06	
43	167	59	14	393	50	None	210	None	19	529
2.5	9.7	3.4	0.82	22.9	2.9		12.3		1.1	
27	123	19	0.8	283	26	9.3	150	18	10	530
1.6	7.2	1.1	0.05	16.5	1.5	0.54	8.8	1.1	0.58	
14.6	67	46	3.6	140	90	1.8	69	18	1.0	531
0.85	3.9	2.7	0.21	8.2	5.3	0.11	4.0	1.1	0.06	
3.6	6.8	122	0.3	....	102	1.5	68	14	None	532
0.21	0.40	7.1	0.02	....	5.9	0.09	4.0	0.82		

TABLE XX

No.	Description		Total solids	Total hardness, CaCO ₃	Carbonate or temporary hardness, CaCO ₃	Non-carbonate or permanent hardness, CaCO ₃
ZANESVILLE—Concluded						
533	Findeiss & Hecket Co., Muskingum and Harrison Sts. Driven well, 59 feet, in gravel, ending at the rock. Pumps 125 gal. per min. Well was originally 40 feet deep but went dry occasionally. Used in tanning. City water is used in boilers along with tanning liquor.	Pts. per mill.	1150	685	372	313
		Grs. per gal.	67.0	40.0	21.7	18.2
534	Marks Manufacturing Co., end of Moxahalla Ave. Driven well, 67 feet, 6½-in. casing. Water level 18 feet from surface. Pumps 100 gal. per min. Used for drinking. Use softened river water in boilers.	Pts. per mill.	1456	980	275	705
		Grs. per gal.	85.0	57.0	16.1	41.1
535	Same location as No. 534. Muskingum River water.	Pts. per mill.	446	225	127	98
		Grs. per gal.	26.0	13.1	7.4	5.7
536	Same location as No. 534. River water after softening with lime and soda ash by We-fu-go system. Ferrous sulfate was also used to help clarify the water.	Pts. per mill.	324	32	(42)	32
		Grs. per gal.	18.9	1.9	....	1.9
537	J. B. Owens Floor & Wall Tile Co., Dearborn St. Drilled well, 65 feet, 4-in. casing, in rock. Used for drinking and cooling gas engines.	Pts. per mill.	208	125	72	53
		Grs. per gal.	12.1	7.3	4.2	3.1
538	Mosaic Tile Co., Cooper Mill Road. Drilled well, 50 feet, 5½-in. casing, ending in quicksand. Pumps 25,000 gal. in 24 hrs. Used for drinking and in manufacture of tile.	Pts. per mill.	882	612	195	417
		Grs. per gal.	51.4	35.7	11.4	24.3

⁴²Normal carbonate = 50 pts. per mill. or 2.9 grs. per gal.
 Hydroxide = 27 pts. per mill. or 1.6 grs. per gal.

GROUND WATERS OF OHIO—Continued

Magnesium, Mg	Calcium, Ca	Sodium (Potassium), Na	Iron, Fe	Bicarbonate ion, HCO ₃	Chloride ion, Cl	Nitrate ion, NO ₃	Sulfate, ion, SO ₄	Silica SiO ₂	Free carbon dioxide CO ₂	No
45	200	92	1.0	454	134	30	189	12	48	533
2.6	11.7	5.4	0.06	26.5	7.8	1.8	11.0	0.70	2.8	
62	290	26	0.14	335	42	4.5	564	50	35	534
3.6	16.9	1.5	0.01	19.6	2.5	0.26	32.9	2.9	2.0	
16	64	40	1.6	155	80	3.5	67	32	3.0	535
0.93	3.7	2.3	0.09	9.0	4.7	0.20	3.9	1.9	0.18	
6.1	2.8	104	0.14	....	76	1.3	71	24	None	536
0.36	0.16	6.1	0.01	....	4.4	0.08	4.1	1.4		
12.2	30	8.0	0.24	88	12	3.0	63	36	31	537
0.71	1.8	0.47	0.01	5.1	0.70	0.18	3.7	2.1	1.8	
49	165	None	0.2	238	10	3.0	342	84	8.0	538
2.9	9.6		0.01	13.9	0.58	0.18	19.9	4.9	0.47	

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